AD-A017 734

ATMOSPHERIC TRANSMITTANCE FROM 0.25 TO 28.5 MICRONS: COMPUTER CODE LOWTRAN 3

J. E. A. Selby, et al

Air Force Cambridge Research Laboratories
Hanscom Air Force Base, Massachusetts

7 May 1975

AFCRL-TR-75-0255
ENVIRONMENTAL RESEARCH PAPERS, NO. 513

Atmospheric Transmittance From 0.25 to 28.5 μm: Computer Code LOWTRAN 3

J. E. A. SELBY
R. A. McCLATCHEY

7 May 1975

Approved for public release; distribution unlimited.

OPTICAL PHYSICS LABORATORY PROJECT 7670
AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
HANSCOM AFB, MASSACHUSETTS 01731

AIR FORCE SYSTEMS COMMAND, USAF

Qualified requestors may obtain additional copies from the Defense Documentation Center. All others should apply to the National Technical Information Service.

AFCRL-TR-75-0255
7 MAY 1975
ENVIRONMENTAL RESEARCH PAPERS, NO. 513

ATMOSPHERIC TRANSMITTANCE FROM 0.25 TO 28.5 μm: COMPUTER CODE LOWTRAN 3

J. E. A. Selby
R. A. McClatchey

Errata

1. Pages 38 through 44—The transmittance curves presented in Figures 5 through 11 should be terminated at 0.25 μm. The figures show an increase in transmittance due to ozone absorption as the wavelength approaches 0.2 μm. However, absorption due to oxygen becomes important below 0.25 μm and has not been taken into account in LOWTRAN 3.

2. Page 69—Line number A 126B and A 134 should read as follows:

```
IF (VIS.GT.0.0) PRINT 417, VIS                                    A 126B
IF (VIS.LE.0.0.AND.IHAZE.GT.0) PRINT 416, IHAZE,HZ(IHAZE)         A 134
```

AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
HANSCOM AFB, MASSACHUSETTS 01731

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFCRL-TR-75-0255	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) ATMOSPHERIC TRANSMITTANCE FROM 0.25 TO 28.5 μm: COMPUTER CODE LOWTRAN 3		5. TYPE OF REPORT & PERIOD COVERED Scientific. Interim.
		6. PERFORMING ORG. REPORT NUMBER ERP No. 513
7. AUTHOR(s) J.E.A. Selby R.A. McClatchey		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Air Force Cambridge Research Laboratories (OP) Hanscom AFB Massachusetts 01731		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62101F 7670 09 01
11. CONTROLLING OFFICE NAME AND ADDRESS Air Force Cambridge Research Laboratories (OP) Hanscom AFB Massachusetts 01731		12. REPORT DATE 7 May 1975
		13. NUMBER OF PAGES ~~100~~ 110
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

TECH, OTHER

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Atmospheric transmittance	Atmospheric optics
Infrared	Radiative transfer
Visible	Attenuation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A Fortran computer program, LOWTRAN 3, is described for calculating the transmittance of the atmosphere in the spectral region from 0.25 to 28.5 μm at a spectral resolution of 20 cm^{-1}. The program provides a choice of six atmospheric models covering seasonal and latitudinal variations from sea level to 100 km, two haze models, and accounts for molecular absorption, molecular scattering, and aerosol extinction. Refraction and earth curvature effects are also included. This program provides some modifications to the molecular absorption and aerosol extinction data provided in an earlier LOWTRAN 2

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. (Cont)

report. In addition, input modifications have been made, making the LOWTRAN 3 program considerably more flexible in terms of the input of meteorological data.

Contents

Illustrations

Tables

Atmospheric Transmittance From 0.25 to 28.5 μm: Computer Code LOWTRAN 3

1. INTRODUCTION

The need for predicting the transmittance of the atmosphere over a broad spectral interval at low resolution is not a new one, and many methods have been proposed to do this. A major problem with most of the techniques is that they are difficult to apply. In order to alleviate this situation and to provide a fairly accurate, simple, and rapid way of estimating atmospheric transmittance in the 0.25 to 28.5 μm region, an empirical graphical prediction scheme was devised using some techniques originally suggested by Altshuler.[1] The prediction scheme is based mainly on recent laboratory transmittance measurements complemented by using available the theoretical molecular line constants in line-by-line transmittance calculations, and is presented by McClatchey et al.[2]

Because of the large amount of interest shown in this work, it was decided to computerize the prediction scheme and to digitize the spectral curves, transmittance functions, and model atmospheres contained in McClatchey et al,[2] which forms the basis of LOWTRAN 3.

(Received for publication 6 May 1975)

1. Altshuler, T.L. (1961) Infrared Transmission and Background Radiation by Clear Atmospheres, GE Report 61 SD 199, AD-401923.

2. McClatchey, R.A., Fenn, R.W., Selby, J.E.A., Volz, F.E., and Garing, J.S. (1972) Optical Properties of the Atmosphere (Third Edition), AFCRL-72-0497.

The Fortran computer code LOWTRAN 3 is designed to calculate the transmittance (averaged over a 20 cm^{-1} interval) for a given atmospheric path at steps of 5 cm^{-1} from 350 to 40,000 cm^{-1} (0.25 to 28.5 μm). A choice of six model atmospheres is given with an option for a seventh model which can be inserted as a set of radiosonde data. Aerosol attenuation is calculated for a given visual range based on an interpolation/extrapolation scheme using two aerosol models (see Section 3.4).

The computer code LOWTRAN 3 supersedes two earlier versions of the program, namely LOWTRAN 1[3] and LOWTRAN 2.[4] LOWTRAN 3 is a modification of the LOWTRAN 2 computer code, and provides an updating of the original data as well as giving more flexibility to the user. The differences between the two programs will be described in detail in the following sections.

For horizontal path transmittance calculations under nonstandard conditions, the user can specify his own meteorological conditions. The amount of water vapor in the path is calculated in LOWTRAN 3 using either dew point temperature or ambient temperature and relative humidity, whichever the user specifies (see Section 3.1).

The card sequence numbering system used in LOWTRAN 2 has been preserved so that workers who are already using LOWTRAN 2 can update their card decks with a minimum of effort. All changes and additions to the latter program have been indicated by a symbol, (for example, , A, B, C, etcetera) against an original sequence number (see Appendix A).

We will first briefly describe the theory and input data used in the program. General instructions for using LOWTRAN 3 are given in Section 5. A series of examples illustrating the input data necessary for making a variety of typical atmospheric transmittance calculations is given in Section 6. A listing of the computer code and data is given in Appendix A, supplemented by a flow chart (Appendix B) and a definition of symbols (Appendix D). An iterative refraction scheme used for one particular application of the program (see Section 6.6) is described in Appendix C. Examples of atmospheric transmittance spectra obtained from LOWTRAN 3 together with comparisons with laboratory and field measurements are given in Section 7.

If any discrepancies are encountered in the program, we would appreciate notification in writing.

---

3. Manley, O.P., Smith, H.J.P., Treve, Y.M., Carpenter, J.W., Degges, T.C., Doan, L.R. (1971) OPTIR II, AFCRL-71-0528 (Vol. 2 & 3)
(1973) OPTIR III, AFCRL-TR-73-0217 and 0491
(1974) OPTIR IIIB, AFCRL-TR-74-0319.

4. Selby, J.E.A., and McClatchey, R.A. (1972) Atmospheric Transmittance from 0.25 to 28.5 μm: Computer Code LOWTRAN 2, AFCRL-72-0745.

2. MODEL ATMOSPHERES

The altitude, pressure, temperature, water vapor density, and ozone density for the U.S. Standard Atmosphere and five seasonal model atmospheres, as well as the number of particles per cm^3 for two haze models – corresponding to sea level visual ranges of 5 and 23 km – are provided as basic input data for LOWTRAN 3. The model atmospheres correspond to the 1962 U.S. Standard Atmosphere[5] and the five supplementary models: that is, Tropical (15°N), Midlatitude Summer (45°N, July), Midlatitude Winter (45°, January), Subarctic Summer (60°N, July), and Subarctic Winter (60°N, January). The different models are digitized in 1 km steps from 0 to 25 km, 5 km steps from 25 to 50 km, then at 70 km and 100 km directly as given by McClatchey et al.[2]

The water vapor and ozone altitude profiles added to the 1962 U.S. Standard Atmosphere by McClatchey et al were obtained from Sissenwine et al[6] and Herring et al[7] respectively, and correspond to mean annual values. The water vapor densities for the 1962 U.S. Standard Atmosphere correspond to relative humidities of approximately 50 percent for altitudes up to 10 km, whereas the relative humidity values for the other supplementary models tend to decrease with altitude from approximately 80 percent at sea level to approximately 30 percent at 10 km altitude.

In addition to the model atmospheres provided in this report, the user has the option of inserting his own model atmosphere [specifically designed for direct insertion of radiosonde data (see Section 6.9)], or of building another model by combining various parts of the six standard models (see Section 6.10).

One major difference between LOWTRAN 3 and LOWTRAN 2 is that the reader no longer has to look up the saturation vapor density of water (from Table 1 in Selby and McClatchey[4]) when using meteorological data as input to the program. In LOWTRAN 3 the actual water vapor density is calculated for a given ambient temperature and relative humidity or dew point temperature using the following empirical expression for the saturation vapor density:

$$F(t) = A \exp\left(18.9766 - 14.9595A - 2.4388A^2\right) \text{ gm m}^{-3}$$

5. Valley, S.L., Ed. (1965) Handbook of Geophysics and Space Environments, AFCRL.

6. Sissenwine, N., Grantham, D.D., Salmela, H.A. (1968) Humidity Up to the Mesopause, AFCRL-68-0550.

7. Herring, W.S., and Borden, T.R. (1964) Ozone Observations Over North America, AFCRL-64-30, Vol. 2.

where

$$A = 273.15/(273.15 + t)$$

and

t is given in °C.

The above expression was found to give a good fit to published values of saturation water vapor density measured over water[8] to better than 1 percent for temperatures between -50°C and 50°C.

If t is the dew point temperature then $F(t)$ gives the actual water vapor density directly at the corresponding ambient temperature. If t is the ambient temperature then the water vapor density is given by $F(t) \times RH/100$ where RH is the percent relative humidity.

Thus the user has a choice of meteorological parameters necessary to specify the amount of water vapor, that is, ambient temperature and relative humidity, or dew point temperature, or water vapor density. The procedure for inserting radiosonde data into the program and the necessary formats are described in Sections 5.3 and 6.8.

3. ATMOSPHERIC CONSTITUENTS

3.1 Atmospheric Gases

It is assumed in this report that mixing ratios of the gases, CO_2, N_2O, CH_4, CO, N_2, and O_2 remain constant at all altitudes at the following values: 330, 0.28, 1.6, 0.075, 7.905×10^5, and 2.095×10^5 parts per million respectively. These gases as a whole, with the exception of nitrogen, will be referred to as the uniformly mixed gases.

Absorption coefficients for water vapor, ozone, and the combined effects of the uniformly mixed gases were digitized from the spectral curves (Figures 16-25)[2] by McClatchey et al and are included as data for LOWTRAN 3. The transmittance spectra from which the coefficients were derived were first degraded in resolution to 20 cm^{-1} and the data points were digitized at steps of 5 cm^{-1}. For the ultraviolet and visible ozone bands (see McClatchey et al, Figure 26),[2] the absorption coefficients were digitized at 200 cm^{-1} and 500 cm^{-1} intervals respectively.

8. List, R.J. (1968) Smithsonian Meteorological Tables (6th revised edition), Smithsonian Institute Press, Washington.

There has been one modification to the spectral data for water vapor* in the 2.7 μm region (since LOWTRAN 2 was published) based on a more recent review of available experimental measurements. The above modification leads to slightly higher atmospheric absorption by water vapor in the 2.2 to 3.4 μm spectral region than given by LOWTRAN 2.

3.2 Continuum Absorption

Absorption coefficients for the water vapor continuum near 10 μm and 4 μm in LOWTRAN 3 are based on measurements of Burch et al, McCoy and Rensch, and Bignell.[9-13] The effect of absorption by the water vapor continuum between 14 μm and 28.5 μm has not been included at this time because there is insufficient data in this region.

The continuum due to collision induced absorption by nitrogen in the 4 μm region is included in LOWTRAN 3 based on the measurements of Reddy and Cho[14] and Shapiro and Gush[15] (see also McClatchey et al[2]).

In all cases the transmittance due to continuum absorption is assumed to follow a simple exponential law.

3.3 Molecular Scattering

The absorption coefficient due to molecular scattering, C6, is introduced into LOWTRAN 3 via the following expression:

$$C6 = 9.87 \times 10^{-20}\ \nu^4\ \mathrm{km}^{-1}$$

where ν is in wavenumbers (cm^{-1}).

The above expression was obtained as a best fit to molecular scattering coefficients published by Penndorf[16] and is shown in Figure 1 together with the aerosol extinction coefficient.

3.4 Aerosol Models

Two aerosol models are incorporated into LOWTRAN 3 and correspond to visual ranges of approximately 5 km and 23 km at sea level. However, an aerosol attenuation for any visual range is calculated by LOWTRAN 3 using an interpolation/extrapolation procedure (described in Section 3.5) which utilizes these two models. As these aerosol models are based on measurements of continental aerosol under moderate visibility conditions, they may not be valid for very low

*Not included in LOWTRAN 2.

NOTE: For references 9-16, see list of References on page 63.

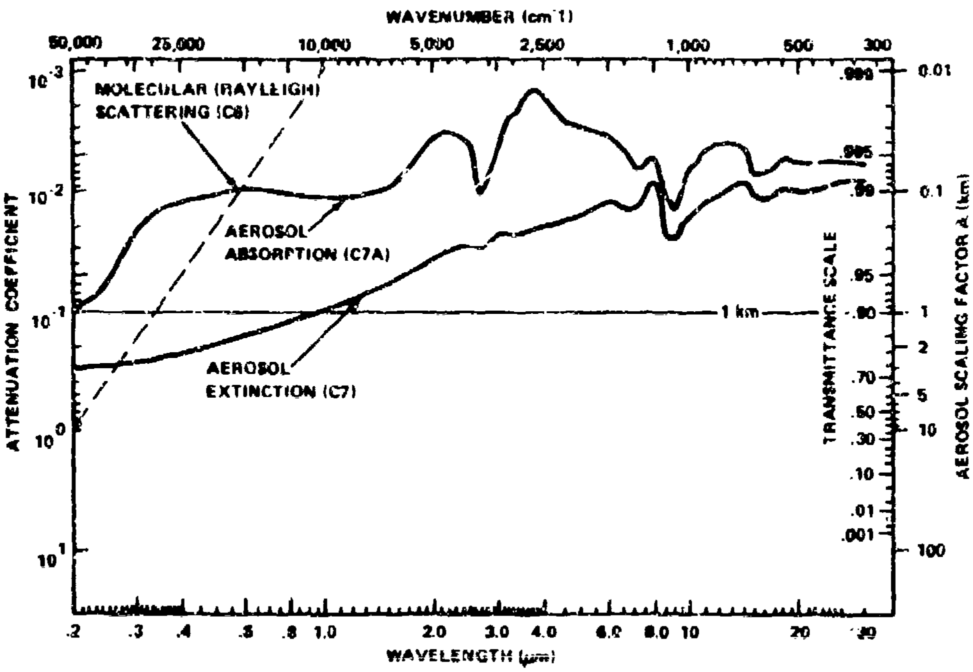


Figure 1. Attenuation Coefficients for Aerosol Transmittance (Absorption and Total Extinction)

visibility conditions less than 2 km. Reported low visibility conditions less than 2 km are probably representative of fog conditions. In this case, the LOWTRAN 3 results will tend to underestimate the attenuation (overestimate the transmittance) in the infrared and overestimate the attenuation in the ultraviolet. A more realistic result can be obtained by assuming the attenuation to be wavelength independent (see McClatchey, et al, 1972, p. 79)[2] and assuming that the aerosol attenuation provided by LOWTRAN 3 at 5500 Å is also valid throughout the infrared and near ultraviolet. The application of this "fog model" should only be applied to the lowest few hundred meters above the surface. In LOWTRAN 3, a message will be printed out to warn the user in the event that results are required for sea level visual ranges less than 2 km. The two aerosol models are based on the following assumptions.

(1) A particle size distribution similar to Deirmendjian's Haze Model C,[17, 18] but where the large particle radius cutoff has been extended to 100 μm (compared

17. Deirmendjian, D. (1964) Appl. Opt. 3:187.

18. Deirmendjian, D. (1969) Electromagnetic Scattering on Spherical Polydispersions, American Elsevier Pub. Co., N.Y.

to 5 μm in Deirmendjian[17] and 10 μm in McClatchey et al[2] and Selby and McClatchey[4]).

(2) The particle size distribution is assumed to remain constant with altitude.

(3) The variation of aerosol number density with altitude is assumed to be the same as previously given by McClatchey et al[2] for the 23 km visual range model. The latter aerosol number densities were adjusted to give extinction coefficients at a wavelength of 0.55 μm that corresponded to those obtained by Elterman[19,20] at each altitude.

(4) The variation of aerosol refractive index with wavelength has been obtained from measurements by Volz[21] (see also McClatchey and Selby[22]), who has found that aerosols are composed of water-soluble substances as well as dust like material.

Aerosol extinction (C7) and aerosol absorption (C7A) values were calculated based on single scattering Mie theory using the above aerosol size distribution and refractive index values (assuming the aerosols to be composed of 70 percent water-soluble substance and 30 percent dust-like substance, which appears to be representative of continental aerosol). Figure 1 shows the variation of the calculated aerosol extinction and absorption coefficients with wavelength. In LOWTRAN 3, (C7) and (C7A) were digitized directly from Figure 1 at discrete wavelengths (see Appendix A and Table A2).

The above aerosol model replaces the empirical function previously used in LOWTRAN 2. Figure 1 can be used to calculate aerosol extinction and absorption in the same way as described in McClatchey et al[2] and replaces Figure 22 in the latter reference.

3.5 Aerosol Interpolation/Extrapolation Scheme

The total extinction coefficient σ_T at 0.55 μm is inversely proportional to visual range, VIS, and can be written as follows (Middleton[23]):

$$\sigma_T = \sigma_a + \sigma_m = \frac{3.91}{VIS} .$$

19. Elterman, L. (1968) UV, Visible and IR Attenuation for Altitudes up to 50 km, AFCRL-68-0153.

20. Elterman, L. (1970) Vertical Attenuation Model with Eight Surface Meteorological Ranges 2 to 13 km, AFCRL-70-0200.

21. Volz, F.E. (1972) Appl.Opt. 11:755.

22. McClatchey, R.A., and Selby, J.E.A. (1974) Atmospheric Attenuation of Laser Radiation from 0.76 to 31.25 μm, AFCRL-TR-74-0003.

23. Middleton, W.E.K. (1952) Vision Through the Atmosphere, Univ. of Toronto Press.

assuming a 2 percent contrast threshold where the suffixes a and m refer to the aerosol and molecular components respectively. The aerosol extinction coefficient can thus be written as

$$\sigma_a = \frac{3.91}{VIS} - \sigma_m .$$

Since the aerosol extinction coefficient σ_a is directly proportional to the aerosol number density N(z), we can write

$$N(z) = \frac{a(z)}{VIS} - b(z) ,$$

where a(z) and b(z) are constants for a given altitude z. It will be noted that b(z) is proportional to the molecular scattering coefficient at $0.55\,\mu m$ at altitude z, where molecular absorption has been assumed negligible at $\lambda = 0.55\,\mu m$.

The above equation forms the basis for the interpolation/extrapolation procedure used in LOWTRAN 3 to determine aerosol attenuation at any given visual range.

The coefficients a and b are determined from the above equation at each altitude using the two aerosol models, that is,

$$a(z) = \left| N_5(z) - N_{23}(z) \right| \Big/ \left| 1/5 - 1/23 \right|$$

$$b(z) = \left| N_{23}(z)/5 - N_5(z)/23 \right| \Big/ \left| 1/5 - 1/23 \right|$$

where N_5 and N_{23} refer to the number densities for the 5-km and 23-km sea level visual ranges. Note that the above procedure is used only in the lower 5 km of the atmosphere since the two aerosol models are identical above 5 km altitude.

4. THEORY

4.1 Basic Assumptions

The computer program LOWTRAN 3 follows almost exactly the procedures outlined by McClatchey et al.[2] The main assumptions made are that the atmosphere can be represented by a 33-layer model, and that the average transmittance $\bar{\tau}$ over a 20 cm^{-1} interval (due to molecular absorption) can be represented by a single parameter model of the form

$$\bar{\tau} = f\,(C_\nu \omega^*) \qquad (1)$$

where C_ν is a wavelength (or wavenumber) dependent absorption coefficient and ω^* is an "equivalent absorber amount" for the atmospheric path, which is defined in terms of the pressure $P(z)$, temperature $T(z)$, concentration of absorber ΔL, and an empirical constant n as follows:

$$\omega^* = \Delta L \left\{ \frac{P(z)}{P_o} \sqrt{\frac{T_o}{T(z)}} \right\}^n . \tag{2}$$

If Eq. (2) is substituted in Eq. (1) and n is set equal to zero and unity, respectively, Eq. (1) reverts to the well known weak line and strong line approximations common to most band models.

The form of the function f and parameter n was determined empirically using both laboratory transmittance data and available molecular line constants. In both cases, the transmittance was degraded in resolution to 20 cm^{-1} throughout the entire spectral range covered here. It was found that the functions f for H_2O and the combined contributions of the uniformly mixed gases were essentially identical, although the parameter n differed in the two cases. Mean values of n were determined to be 0.9 for H_2O, 0.75 for the uniformly mixed gases, and 0.4 for ozone.

4.2 Earth Curvature and Refraction

In general, earth curvature has a greater influence on the path length (and hence on the transmittance) than atmospheric refraction. For long slant paths with zenith angles close to 90° in the lower layers of the atmosphere, however, refractive effects can cause a significant increase in the path length (up to 30 percent for a 90° path to space from ground level). Figure 2 shows the effect of atmospheric refraction on defining the minimum height of a path trajectory from space. The minimum height referred to here is also known as the tangent height. In Figure 2, the difference between the geometrical (no refraction) and the actual minimum height is plotted against the actual minimum height for three different model atmospheres. The sketch in the upper right-hand corner of Figure 2 indicates that there is also a discrepancy in the earth center angle β subtended by the trajectory, when refraction is significant. The difference $\beta - \beta'$ shown in Figure 2 is equal to the total angular deviation ψ of the trajectory due to refraction.

For many applications it is necessary to account not only for the effect of refraction and earth curvature on the transmittance over a given path trajectory, but also on the purely geometrical aspects of the trajectory itself. For example, the total deviation ψ, angle of arrival ϕ, or angle β subtended by the path trajectory may be required as illustrated in Figure 3. LOWTRAN 3 calculates the quantities ψ, ϕ, β and slant range on the basis of a layered atmosphere in the following paragraphs.

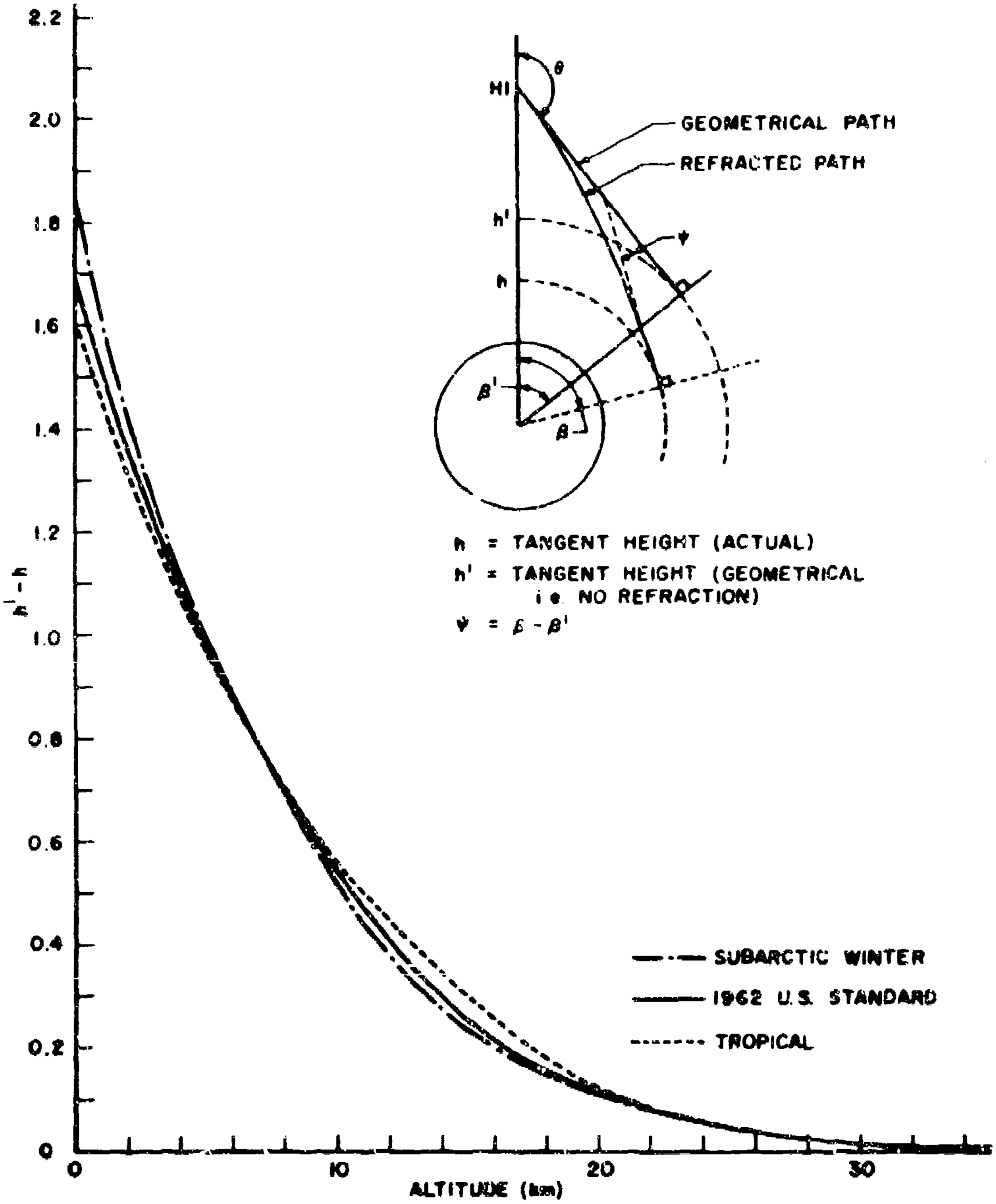


Figure 2. The Difference Between Unrefracted and Refracted Tangent Height Positions as a Function of Altitude for Three Model Atmospheres Based on the 33-Layer Model

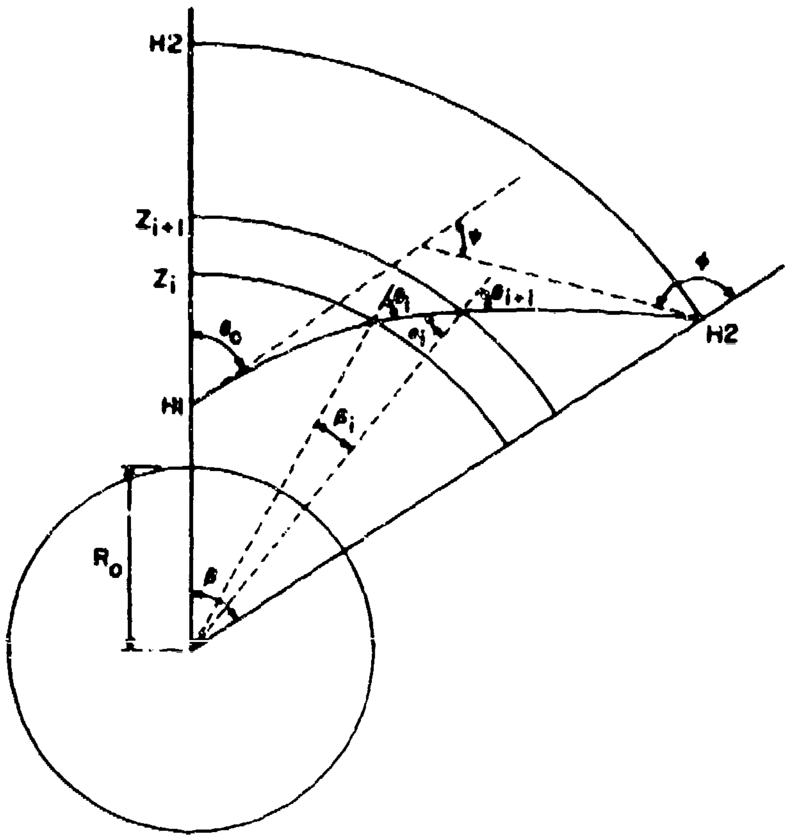


Figure 3. General Schematic of a Refracted Path From Altitudes H1 to H2 Showing the Angles Defining the Trajectory. Initial zenith angle θ_o at H1, angle of arrival ϕ at H2, total angular deviation ψ, and angle subtended by path at the earth's center, β

The earth's atmosphere is assumed to be divided into a series of concentric spherical layers for each of which a mean refractive index is defined. However, the non-sphericity of the earth is taken into account to some extent by using a different earth radius for each latitude (associated with a given model atmosphere).

Consider the trajectory of a ray passing from heights H1 to H2 at an initial zenith angle θ_o. Let z_i and z_{i+1} define the boundary heights of a given layer, and let θ_i and θ_{i+1} be the local zenith angles at the respective boundaries (see Figure 3). Then at a height of z_{i+1}, the angle of refraction is θ_{i+1}. The angle of incidence α_i at height z_{i+1} can be defined as

$$\sin \alpha_i = (R_o + z_i) \sin \theta_i / (R_o + z_{i+1}). \tag{3}$$

Applying Snell's law at boundary z_{i+1}, we have

$$n_i \sin \alpha_i = n_{i+1} \sin \theta_{i+1} \tag{4}$$

where n_i and n_{i+1} are the mean refractive indices of the layers above z_i and z_{i+1} respectively.

Substituting for $\sin \alpha_i$ in Eq. (4), we have

$$n_i (R_o + z_i) \sin \theta_i = n_{i+1} (R_o + z_{i+1}) \sin \theta_{i+1} . \tag{5}$$

It follows from symmetry that

$$\begin{aligned} n_i (R_o + z_i) \sin \theta_i &= n_{i-1} (R_o + z_{i-1}) \sin \theta_{i-1} \\ &= n_o (R_o + H1) \sin \theta_o \\ &= \text{const.} \end{aligned} \tag{6}$$

Therefore, the angle of refraction at any level z can be written in terms of the initial input conditions and the refractive index n_o of the layer above H1 as

$$\sin \theta = n_o (R_o + H1) \sin \theta_o / n (R_o + z) . \tag{7}$$

The angle β_i subtended at the center of the earth by the intersection of the ray with the layer z_i to z_{i+1} is given by

$$\beta_i = \theta_i - \alpha_i . \tag{8}$$

Thus the total earth center angle subtended by the ray when traversing the atmosphere from H1 to H2 is

$$\beta = \sum_i^{m-1} (\theta_i - \alpha_i) \tag{9}$$

$$= \sum_i^{m-1} \left| \sin^{-1} \left\{ A / n_i (R_o + z_i) \right\} - \sin^{-1} \left\{ A / n_i (R_o + z_{i+1}) \right\} \right| \tag{10}$$

where m is the number of levels between H1 and H2, and $A = n_o (R_o + H1) \sin \theta_o$.

The angle of arrival ϕ of the ray at H_2 is given by

$$\phi = 180° - \sin^{-1} \left\{ A / n_{m-1} (R_o + H2) \right\} . \tag{11}$$

The total angular deviation of the trajectory Ψ is given by

$$\Psi = \beta - \phi - \theta_0 + 180 \ . \tag{12}$$

The effective path length between levels z_i and z_{i+1} is given by

$$DS_i = (R_0 + z_{i+1}) \sin \beta_i / \sin \theta_i \quad \text{for } 0° < \theta < 180° \tag{13}$$

for $\theta = 0°$ and $180°$, $DS_i = a_{i+1} - z_i$. If we assume that the equivalent absorber amount per unit path length ω (see Section 4.1) for a given gas varies exponentially with altitude, we can write

$$\int_{z_i}^{z_{i+1}} \omega \, dz = H_i \left[\omega(z_i) - \omega(z_{i+1})\right] \tag{14}$$

where $H_i = (z_{i+1} - z_i)/\log_e\left[\omega(z_i)/\omega(z_{i+1})\right]$. The amount of absorber W_i along a path of length DS_i between altitudes z_i and z_{i+1} is therefore given by:

$$W_i = \int_0^{DS_i} \omega \, ds$$

$$= \frac{DS_i}{z_{i+1} - z_i} \int_{z_i}^{z_{i+1}} \omega \, dz$$

$$= \frac{DS_i\left[\omega(z_i) - \omega(z_{i+1})\right]}{\log_e\left[\omega(z_i)/\omega(z_{i+1})\right]} . \tag{15}$$

The total equivalent absorber amount W for a given atmospheric path is given by the sum of the W_i values for all layers; that is, $W = \sum_{i=1}^{m-1} W_i$ where m is the number of levels traversed by the path.

4.3 Refractive Index of Air

The following simplified version of Edlen's[24] expression for the refractive index of air is used in LOWTRAN 3:

$$\left(n_a - 1\right) 10^{+6} = \left(77.46 + \frac{0.459}{\lambda^2}\right) \frac{P}{T} - \frac{P_{H_2O}}{1013} \left(43.49 - \frac{0.347}{\lambda^2}\right).$$

24. Edlen, B. (1966) Metrologia 2:12.

where p_{H_2O} and P refer respectively to the partial pressure of water vapor and atmospheric pressure in millibars, T is atmospheric temperature in degrees Kelvin, and λ is the wavelength in micrometers (μm).

The above expression has been used over the entire wavelength range 0.2 to 28.5 μm in LOWTRAN 3. Although Edlen's expression for the refractive index of air is widely used in both the visible and infrared spectral regions, it is questionable how far it should be used into the ultraviolet and into the far infrared since the formula is based primarily on measurements made in the visible part of the spectrum from 0.43 to 0.8 μm.

4.4 Geometrical Path Configurations

When using LOWTRAN 3, the type of atmospheric path for which a calculation is to be made must be specified according to one of the three broad categories listed below.

TYPE 1. Horizontal path: that is, a constant pressure path where the effects of earth curvature and refraction are negligible.

TYPE 2. Slant paths between two altitudes from H1 to H2.

TYPE 3. Slant paths to space from initial altitude H1.

The variations within the latter two categories for both upward and downward path trajectories can be seen from Figure 4.

It will be noted that two trajectories are possible for a given set of input parameters, H1, H2, and θ for a downward looking path (TYPE 2), provided that H2 lies between H1 and the minimum height, HMIN.

In most instances, the reader will not be aware that two paths are possible for a given set of input conditions. For such a case, LOWTRAN 3 will execute the shorter path condition [Figure 4(d)] and print out a message to the effect that the case shown in Figure 4(e) does exist. Should the reader decide to run the latter case, he need only set the parameter LEN equal to unity and resubmit the case. This will be seen more clearly from the following section (also Section 6.4).

5. INSTRUCTIONS FOR USING LOWTRAN 3

The input data for LOWTRAN 3 are given in Appendix A. In general, it is only necessary to change the last four cards (referred to here as Nos. 1-4)† in order to run the program for a given problem. The formats for the last four cards and their application will next be discussed.

† These four cards were referred to as Nos. 470-473 in the LOWTRAN 2 report.

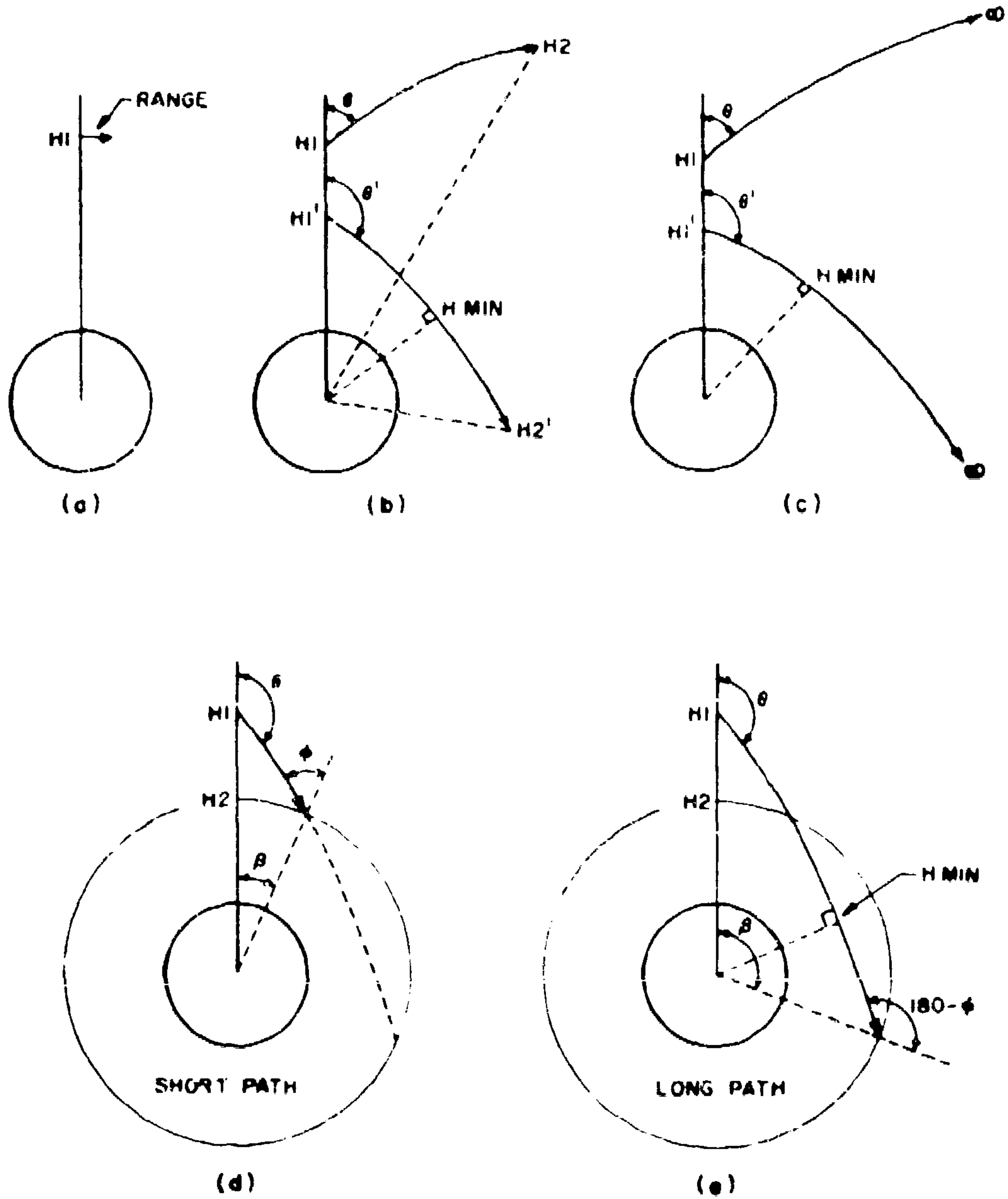


Figure 4. Geometrical Path Configuration for: (a) Horizontal Paths (Type 1), (b) Slant Paths Between Two Altitudes H1 and H2 (Type 2), and (c) Slant Paths to Space (Type 3). For downward looking paths where HMIN < H2 < H1, two trajectories are possible as indicated in (d) and (e).

5.1 Input Data and Formats

The data necessary to specify a given problem are given on the last four cards as follows

CARD 1	MODEL, IHAZE, ITYPE, LEN, JP, IM, M1, M2, M3, ML, R0	{FORMAT (10I3, F10.3)}
CARD 2	H1, H2, ANGLE, RANGE, BETA, VIS	{FORMAT (6F10.3)}
CARD 3	V1, V2, DV	{FORMAT (3F10.3)}
CARD 4	INY	{FORMAT (I3)}.

Definitions of the above quantities will be discussed in Section 5.2.

If the quantity MODEL given on CARD 1 is set equal to 0 or 7 (which is the case if meteorological data are used as input to the program), then the above card sequence (and format for CARD 2) is changed. These cases will be described in Section 5.3 and examples for some typical problems will be given in Sections 6.7 and 6.8.

5.2 Basic Instructions

The various quantities to be specified on each of the four control cards (summarized in Section 5.1) will be discussed in this section.

5.2.1 CARD 1 MODEL, IHAZE, ITYPE, LEN, JP, IM, M1, M2, M3, ML, R0

The parameter MODEL selects one of the six geographical model atmospheres or specifies that meteorological data are to be used in place of the standard models. IHAZE specifies whether aerosol attenuation is to be included in the calculation or not. For any problem the atmospheric path must be specified as one of three types according to ITYPE and LEN. The rest of the quantities given on CARD 1† (which can be left blank if not required) provide the user with options to suppress printing (JP), to intermix the six standard model atmospheres (M1, M2, M3) and to input a new model atmosphere (IM, ML). The options for the above parameters and their uses are stated and described in detail below:

MODEL = 0 if meteorological data are specified (for horizontal paths only)‡

= 1 selects TROPICAL MODEL ATMOSPHERE

= 2 selects MIDLATITUDE SUMMER

= 3 selects MIDLATITUDE WINTER

= 4 selects SUBARCTIC SUMMER

= 5 selects SUBARCTIC WINTER

= 6 selects 1962 US STANDARD

= 7 if a new model atmosphere (or radiosonde data) is to be inserted.‡

---

† The parameters JP, IM, etc. given on CARD 1 were not included in LOWTRAN 2.

‡ In these cases the format for CARD 2 changes (see nonstandard conditions) Section 5.3 and examples 7 and 8 (Section 6.7 and 6.8).

IHAZE = 0 means no aerosol attenuation included in the calculations.

IHAZE = 1 or 2 if aerosol attenuation is required (see also CARD 2).

If IHAZE is set equal to 1 or 2 and visual range (VIS) is not specified on CARD 2, then the program will automatically select visual ranges of 23 km or 5 km respectively.

ITYPE = 1 for a horizontal (constant pressure) path.

= 2 for a vertical or slant path between two altitudes.

= 3 for a vertical or slant path to space.

The TYPE 1 path should not be confused with a long 90° path where the local height of the end of the trajectory is at a significantly different height. In such a case, specify the path according to ITYPE = 2 (see Section 5.2.2).

LEN = 0 for normal operation of program.

LEN = 1 selects the downward TYPE 2 path shown in Figure 4(e).

The parameter LEN can be ignored (that is, left blank) for the majority of cases. It need only be used for a downward looking path (H2 < H1) when two paths are possible for the same input parameters (see Section 4.4). In such a case, a computer printout statement will be given indicating that the user has two choices for the problem and that the shorter path [see Figure 4(d)] has been executed. Set LEN = 1 for the longer case (an example of this is given in Section 6.4).

JP = 0 for normal operation of program.

JP = 1 to suppress printing of transmittance table (see Table 1)

IM = 1 when radiosonde data are to be read in initially

IM = 0 for normal operation of program or when subsequent calculations are to be run with MODEL = 7

ML = number of levels to be read in for MODEL = 7

Note that IM and ML are only used when MODEL = 7 and then only on the first calculation when the data are read in.

M1 = M2 = M3 = 0 for normal operation of program.

The parameters M1, M2, and M3 can each take integral values between 0 and 6 and are used to modify or supplement the altitude profiles of temperature, water vapor, and ozone respectively, for any given atmospheric model specified by MODEL. For example:

M1 = 1 selects the TROPICAL temperature altitude profile

M1 = 2 selects the MIDLATITUDE SUMMER temperature altitude profile

M1 = 6 selects the 1962 US STANDARD temperature altitude profile

M2 = 1 selects the TROPICAL water vapor altitude profile

M2 = 2 selects the MIDLATITUDE SUMMER water vapor altitude profile

M2 = 6 selects the 1962 US STANDARD water vapor altitude profile

M3 = 1 selects the TROPICAL ozone altitude profile

M3 = 2 selects the MIDLATITUDE SUMMER ozone altitude profile

M3 = 6 selects the 1962 US STANDARD ozone altitude profile

R0 = radius of the earth (km) at the particular geographical location at which the calculation is to be performed.

If R0 is left blank, the program will use the midlatitude value of 6371.23 km if MODEL is set equal to zero or 7. Otherwise the earth radius for the appropriate standard model atmosphere (specified by MODEL) will be used.

The use of the parameters defined above will become more apparent by referring to the examples given in Section 6.

In the case where MODEL = 7, the new atmosphere (model or radiosonde data) is inserted between CARDS 1 and 2 (see Section 5.3).

5.2.2 CARD 2 H1, H2, ANGLE, RANGE, BETA, VIS

Card 2 is used to define the geometrical path parameters for a given problem.

H1 = initial altitude (km)

H2 = final altitude (km)

ANGLE = initial zenith angle (degrees) as measured from H1

RANGE = path length (km)

BETA = earth centre angle subtended by H1 and H2 (degrees)

VIS = sea level visual range (km)

It is not necessary to specify every quantity given above; only those that adequately describe the problem according to the parameter ITYPE (as described below).

(1) Horizontal Paths (ITYPE = 1)

(a) specify H1, RANGE and VIS only

(b) if nonstandard meteorological data are to be used, that is, if MODEL = 0 on CARD 1), then the following parameters must be specified on CARD 2: H1, P, T, DP, RH, WH, WO, VIS, RANGE according to FORMAT (3F10.3, 2F5.1, 2E10.3, 2F10.3), where P, T, DP, RH, WH and WO are the pressure (mb), temperature (°C), dew point temperature (°C), relative humidity (%), H_2O density (gm m^{-3}) and ozone density (gm m^{-3}) respectively.

Note that it is necessary to specify all of the quantities underlined with a full line and one of the quantities underlined with a dashed line. If the ozone density (WO) is not known, a value can be chosen from one of the standard atmospheric models by using the parameter M3 on CARD 1 (see Section 5.2.1 above).

Some examples of typical horizontal path calculations are given in Sections 6.1 and 6.8.

(2) Slant Paths to Space (ITYPE = 3)

(a) specify H1, ANGLE and VIS

(b) specify H1, HMIN and VIS (for limb viewing problem where HMIN is the required tangent height or minimum altitude of the path trajectory.

(3) Slant Paths Between Two Altitudes (ITYPE = 2)

(a) specify H1, H2, ANGLE and VIS

(b) specify H1, ANGLE, RANGE and VIS

(c) specify H1, H2, RANGE and VIS

For cases (b) and (c), the program will calculate H2 and ANGLE respectively, assuming no refraction; then proceed as for case (a). This method of defining the problem should be used when refraction effects are not important; for example, for ranges of a few tens of km at zenith angles less than 80°. It can also be used for larger angles (including 90°) provided that the path lies within one atmospheric layer.

(d) Specify H1, H2, BETA and VIS. Leave ANGLE and RANGE blank in this case. This method can be used when the geometrical configuration of the source and receiver is known accurately, but the initial zenith angle is not known precisely due to atmospheric refraction effects. Beta is most frequently determined by the user from ground range information.

In the cases of 2(b) and 3(d) above, the subroutine ANGLE is called in the program to determine the appropriate input zenith angle by an iterative technique taking into account atmospheric refraction (see Appendix C).

In the case where MODEL = 7, the new model atmosphere (or radiosonde data) is inserted between CARDS 1 and 2 (see Section 5.3).

5.2.3 CARD 3 V1, V2, DV

The spectral range over which transmittance data are required and the spectral increments at which the data are to be printed out is determined by CARD 3.

V1 = initial frequency in wavenumbers (cm^{-1})

V2 = final frequency in wavenumbers (cm^{-1}) where $V2 > V1$

DV = frequency increment (or step size) (cm^{-1})

(Note that $\nu = 10^4/\lambda$ where ν is the frequency in cm^{-1} and λ is the wavelength in microns, and that DV can only take values which are a multiple of 5.)

5.2.4 CARD 4 IXY

The control parameter IXY can cause the program to recycle, so that a series of problems can be run with one submission of LOWTRAN 3. Five values of IXY can be used to provide the options given below.

IXY = 0 or blank card to end of program

= 1 to select a new CARD 3 and CARD 4 only (assuming other parameters are unchanged)

= 2 to select a new data sequence (CARDS 1, 2, 3, and 4)

= 3 to select a new CARD 2 and CARD 4 only (assuming other parameters are unchanged)

= 4 to select a new CARD 1 and CARD 4 only (assuming other parameters are unchanged)

Thus, if for the same model atmosphere and type of atmospheric path the reader wishes to make further transmittance calculations in different spectral intervals V1' to V2' etc. and for a different step size (DV' etc.), then IXY is set equal to 1. In this case, the card sequence is as follows and can be repeated as many times as required:

CARD 4 IXY = 1

CARD 5 V1' V2' DV'

CARD 6 IXY = 1

CARD 7 V1'' V2'' DV''

CARD 8 IXY = 0

The final IXY card should always be a blank or zero (see also Section 6.2). When using the IXY = 1 option, the wavelength dependence of the refractive index is not changed (use IXY = 2 option if this is required).

To make successive transmittance computations where just the geographical model atmosphere is changed and/or with or without aerosol attenuation, set IXY = 4 and construct a data card sequence along the same lines as given above. This sequence of recycling can be repeated successively, and several examples are given in Section 6.

5.2.5 PROBLEM SEQUENCING

When a series of problems is to be executed (with one submission of LOWTRAN 3) involving the standard atmospheric models (MODEL = 1 to 6) as well as cases involving MODEL = 0 and MODEL = 7, then the order in which the data are set up becomes very important. Note the following sequence.

1. Run all problems using MODEL = 1 through 6 first.

2. Secondly, run all problems involving the use of MODEL = 0.

3. Run all problems involving the use of MODEL = 7 last. The reason for running MODEL = 7 cases last is that when a new atmospheric model is read in, the altitudes may not correspond with those given in the standard models (see Section 2.1) and the program will erase them. Similarly, if a MODEL = 0 case is run following a MODEL = 7 case, the first level of MODEL 7 is erased.

5.3 Non-Standard Conditions

Three options are available if atmospheric transmittance calculations are required for non-standard conditions. Here non-standard refers t conditions other

than those specified by the six model atmospheres provided by LOWTRAN 3 (see Section 2.1), which are selected by the parameter MODEL on CARD 1 (see Section 5.2.1). The three options enable the reader to insert:

(1) his own model atmopshere(s) in place of any (or all) of the six standard models, provided that the data are in exactly the same format and are specified at the same altitudes as the latter. In this case the appropriate print statements in LOWTRAN 3 (that identify the atmospheric model used) must be changed correspondingly.

(2) an additional atmospheric model (MODEL 7), which can be in the form of radiosonde data. The data need not be specified at the same altitudes as in the standard models.

(3) meteorological conditions for a given horizontal path calculation (MODEL = 0 case).

The first of these options requires the most effort and needs no further discussion here, other than a reference to Appendix A for a summary of the standard model atmosphere parameters, units and formats (see also Table A2).

5.3.1 ADDITIONAL ATMOSPHERIC MODEL (MODEL = 7)

As stated in Section 5.2.2 a new model atmosphere can be inserted between CARDS 1 and 2 provided the parameters MODEL and IM are set equal to 7 and 1 respectively on CARD 1. The number of atmospheric levels to be inserted (ML) must also be specified on CARD 1. The appropriate meteorological parameters and format for the atmospheric data are given below.

Z, P, T, DP, RH, WH, WO, AHAZE [FORMAT (3F10.3, 2F5.1, 2E10.3, 2F10.3)] where

Z = altitude (km)

P = pressure

T = ambient temperature (°C)

DP = dew point temperature (°C)

RH = relative humidity (%)

WH = water vapor density (gm m^{-3})

WO = ozone density (gm m^{-3})

AHAZE = aerosol number density (cm^{-3})

Note that it is only necessary to specify those quantities underlined with a full line and either of the quantities underlined with the dashed line.

If the ozone density (WO) is not known then a value can be obtained from one of the standard atmospheric models (for the appropriate latitude and season) by using the parameter M3 on CARD 1 (see Section 5.2.1).

If the aerosol number density was not measured as a function of altitude and the reader wishes to include aerosol attenuation in the calculation, set IHAZE = 1

on CARD 1. In this case (as with the M1, N2, and M3 options) LOWTRAN 3 will use the aerosol models already contained in the program and interpolate to give aerosol number density values at the same altitudes as the radiosonde (or new model atmosphere) data.† The program will then look for a sea level visual range (VIS) to be specified on CARD 2. If VIS is not specified, a 23 km sea level visual range will be assumed. If aerosol attenuation is not required, set IHAZE = 0 on CARD 1 as before.

5.3.2 HORIZONTAL PATHS (MODEL = 0)

If meteorological data are to be used for horizontal path atmospheric transmittance calculations, then set MODEL = 0 on CARD 1. The following parameters can then be specified on CARD 2:

CARD 2 H1, P, T, DP, RH, WH, WO, VIS, RANGE [FORMAT (3F10.3, 2F5.1, 2E10.3, 2F10.3)] where the above parameters refer to altitude (km), pressure (mb) ambient temperature (°C),‡ dew point temperature (°C), relative humidity (%), water vapor density (gm m^{-3}), ozone density (gm m^{-3}), visual range (km) and path length (km) respectively (as previously defined in Sections 5.3.1 and 5.2.2).

The format for the above card is similar to that for inputting radiosonde data (MODEL = 7) described in Section 5.3.1 above. Again, it is only necessary to specify the quantities underlined with the solid line and one of the quantities underlined with the dashed line. The ozone density WO can be specified using the parameter M3 on CARD 1 if measurements are not available. In the latter case, a value will be calculated at altitude H1 based on the appropriate model atmosphere selected by M3.

6. EXAMPLES

The following examples explain the problem parameters that need to be specified and card formats necessary for using LOWTRAN 3 to make a wide range of atmospheric transmittance calculations. Example 9 describes how the reader may insert an additional model atmosphere (for example, a set of radiosonde or rawinsonde data) into the program.

As mentioned earlier, only the last four data cards (see Table A2 in Appendix A) are necessary to specify a given problem. It should be noted that the

† A similar interpolation scheme is applied when the M1, M2 and M3 options are used to supplement MODEL 7 (and also for MODEL = 0) using the standard atmospheric models.

‡ Note that temperature is given in °C for MODEL = 0 option and not °K as previously used in LOWTRAN 2.

terms "CARD 1, CARD 2, etc." are used for convenience to denote these important control cards in their correct sequence, and do not refer to the actual first, second, etc. data cards in LOWTRAN 3 (described in Appendix A).

6.1 Example 1 - Horizontal Path Calculations (ITYPE = 1)

PROBLEM AND CARD FORMAT

Calculate the transmittance from 500 cm^{-1} to 1000 cm^{-1} in steps of 5 cm^{-1} for a horizontal path of range 10 km at an altitude of 2.5 km, for a midlatitude summer model atmosphere and the 5 km (sea level) visual range haze model.

```
CARD 1   **2**1**1
CARD 2   *****2.500************************10.000***************5.000
CARD 3   ***500.000**1000.000*****5.000
CARD 4   ***
```

or alternatively

```
CARD 1   **2**2**1
CARD 2   *****2.500**************************10.0
CARD 3   ***500.000**1000.000******5.0
CARD 4   Blank
```

(* represents a space on the card.)

Note that setting IHAZE = 2 can select a 5 km visual range at sea level without setting VIS on CARD 2.

6.2 Example 2 - Slant Path Calculation to Space (ITYPE = 3) for Two Spectral Intervals

PROBLEM AND CARD FORMAT

Calculate the transmittance from 3 to 5 μm and 8 to 14 μm in steps of ~0.05 μm for a 45° slant path to space from 12.2 km, for a midlatitude winter model atmosphere and a 23 km visual range haze model.

In this case V1 = 2000 cm^{-1}, V2 = 3335 cm^{-1}, and DV varies from 20 cm^{-1} to 55.5 cm^{-1}. Let us choose the lower value, that is, DV = 20 cm^{-1}; also, V1' = 714 cm^{-1} and V2' = 1250 cm^{-1} with DV' varying from 2.55 cm^{-1} to 7.81 cm^{-1}. Thus DV' = 5 cm^{-1}, since this is the nearest multiple of 5 cm^{-1}.

```
CARD 1   **3**1**3
CARD 2   ****12.200****************45.0
CARD 3   **2000.000**3335.000******20.0
CARD 4   **1
CARD 5   ***714.000**1250.000******5.00
CARD 6   Blank
```

Note setting IHAZE = 1 on CARD 1 will select a 23 km sea level visual range if VIS is not set on CARD 2.

6.3 Example 3 - Upward Looking Slant Path Calculation (ITYPE = 2)

PROBLEM AND CARD FORMAT

Calculate the transmittance from 4 to 5 μm in steps of ~0.01 μm for a slant path from 2.25 km to 22.8 km at zenith angle of 65°, for a subarctic winter model atmosphere and a 15 km (sea level) visual range haze model.

In this case V1 = 2000 cm^{-1}, V2 = 2500 cm^{-1}, and DV varies from 4 cm^{-1} to 6.26 cm^{-1}. Therefore, set DV = 5 cm^{-1} since this is the nearest multiple of 5 cm^{-1}.

CARD 1 **5**1**2

CARD 2 ******2.25******8.50******65.0**************************15.000

CARD 3 **2000.000**2500.000*******5.0

CARD 4 Blank

6.4 Example 4 - Slant Path Between Two Altitudes Looking Downward (ITYPE = 2)

PROBLEM AND CARD FORMAT

Suppose the transmittance from 10 to 20 μm is required for a downward path from 10 km to 8 km at a zenith angle of 92°, using the 1962 US Standard Model Atmosphere and no haze.

In this case set V1 = 500 cm^{-1} (20 μm), V2 = 1000 cm^{-1} (10 μm) and DV = 5 cm^{-1}.

CARD 1 **6**0**2

CARD 2 ****10.000*****8.000****92.000

CARD 3 ***500.000**1000.000*****5.000

CARD 4 Blank

When this case is executed, however, there will be a message printed out to the effect that a longer path is also possible for the same input conditions [for example, see Figures 3(d) and 3(e)]. If you wish to rerun the conditions for the longer path, the card sequence is as follows:

CARD 1 **6**0**2**1

CARD 2 ****10.000*****8.000****92.000

CARD 3 ***500.000**1000.000*****5.000

CARD 4 Blank

6.5 Example 5 - Repeated Problems in Sequence

PROBLEM AND CARD FORMAT

Calculate the transmittance for the 4 to 8 μm region for (1) a 75° zenith angle slant path from 0.23 km to 8.55 km for tropical, midlatitude summer and subarctic summer conditions, and (2) for horizontal paths of 1, 5, and 10 km at

5 km altitude for midlatitude summer conditions. In both cases, assume the sea level visual range to be 15 km.

The set up cards for the above problems are as follows:

```
CARD 1   **1**1**2
CARD 2   *****0.230*****8.550****75.000************************15.000
CARD 3   **1250.000**2500.000*****5.000
CARD 4   **4
CARD 5   **2**1**2
CARD 6   **4
CARD 7   **4**1**2
CARD 8   **2
CARD 9   **2**1**1
CARD 10  *****5.000*************************1.000†
CARD 11  **1250.000**2500.000*****5.000
CARD 12  **3
CARD 13  *****5.000*************************5.000†
CARD 14  **3
CARD 15  *****5.000************************10.000†
CARD 16  ***
```

6.6 Example 6 - To Calculate Viewing Angle, Taking Into Account the Effect of Refraction

PROBLEM AND CARD FORMAT

Suppose the exact position of a source and receiver is known; that is, H1, H2, and geometrical range. From this, one can calculate the apparent zenith angle (assuming no refraction) and the total angle subtended by the path at the center of the earth, β (see Figure 3). If the apparent zenith angle is such that atmospheric refraction could cause appreciable bending of the path trajectory, then the receiver could be considerably off target. To take into account the effect of atmospheric refraction, one can use the subroutine ANGLE (with H1, H2, and BETA as inputs) which is called by the program to determine the correct zenith angle.

Suppose Example 4 was the above case where $\beta = 5.3715°$ is known specifically for the shorter path. The card sequence would then be:

```
CARD 1   **6**0**2
CARD 2   ****10.000*****8.000************************5.3715
CARD 3   ***500.000**1000.000*****5.000
CARD 4   Blank
```

† Since the aerosol attenuation models are independent of sea level visual range above 5 km altitude, it is not necessary to specify VIS in this case.

6.7 Example 7 - Earth Limb Viewing Case

PROBLEM AND CARD FORMAT

Consider an earth limb viewing problem where it is required to calculate the atmospheric transmittance from, say, an altitude of 100 km to space passing through a tangent height (HMIN) of 12 km (see Figure 4c), in the 2 to 5 μm region for a subarctic winter model atmosphere. In this case let us assume that aerosol attenuation is required. As described in Section 5.2.2, only the quantities H1 and HMIN are specified on CARD 2. The appropriate zenith angle (taking into account atmospheric refraction) is calculated by the program using the subroutine ANGL.

CARD 1 ****5****1****3

CARD 2 ***100.000****12.000

CARD 3 **2000.000**2500.000*****5.000

CARD 4 ***

6.8 Example 8 - Horizontal Path with Non-Standard Conditions

If the appropriate conditions are known for the horizontal path, then a different procedure to that given in Examples 1 to 7 can be used. For this case, CARD 2 (see Sections 5.1 and 5.2) contains the following information:†
altitude (km), pressure (mb), ambient temperature (°C), dew point temperature (°C), relative humidity (%), water vapor density (gm.m^{-3}), ozone density (gm.m^{-3}), sea level visual range (km), and path length (km) according to format (3F10.3, 2F5.2, 2E10.3, 2F10.3).

PROBLEM AND CARD FORMAT

Calculate the transmittance from 3 to 5 μm for a 10 km path at sea level (midlatitude winter environment) for the following conditions: Pressure = 1000 mb, ambient temperature = 10°C, relative humidity = 40%, and sea level visual range = 50 km.

CARD 1 ****0****1****1****0****0****0****0****0****3

CARD 2 *****0.000**1000.000****10.000*****40.00********************
50.000****10.000

CARD 3 **2000.000**3330.000*****5.000

CARD 4 ***

The index 3 on CARD 1 corresponds to the parameter M3 (see Section 5.2) and selects the ozone density corresponding to the midlatitude winter model atmosphere, since the latter quantity is not specified in the above problem. If M3

† Note that this problem is specified differently in LOWTRAN 2.

were left blank, then ozone attenuation would not be included in the transmittance calculation.

If a number of different problems are being run with one submission of the program involving the standard model atmospheres as well as problems similar to Example 6.8, then the order in which the problems are run becomes important (see Section 5.3).

6.9 Example 9 - To Insert or Change Model Atmosphere Data

If the reader wishes to include his own model atmosphere data in LOWTRAN 3 two options are available. Either replace one or more of the standard models by the new data or use the MODEL = 7 option which is more convenient. If the former approach is taken, it is recommended that the new atmospheric data be digitized at the same altitudes and according to the same format as the remaining standard models (see Appendix A and Table A2). Note that each of the standard model atmosphere data cards contain the following: altitude (km), pressure (mb), temperature (°K), water vapor density (gm.m^{-3}), and ozone density (gm.m^{-3}) with two models specified on one card (see Table A2) according to format (F6.1, 2E10.3, F6.1, 2E10.7).

In the above case, the reader should modify the appropriate print statements in the program accordingly in order to identify the new model atmospheres, otherwise the printout from LOWTRAN 3 will identify them according to the standard atmospheric models which they replaced.

If the reader wishes to make a limited number of atmospheric transmittance calculations for one or more sets of radiosonde (or rawinsonde) data, it is more convenient to use the MODEL = 7 option; an example of which is given below.

PROBLEM AND CARD FORMAT

Calculate for a given set of radiosonde data the transmittance in the 4 to 8 μm region for (1) a slant path from 0.21 km to 8.55 km at a zenith angle of 35.5° and (2) horizontal paths of 1, 5, and 10 km at 0.21 km altitude. Assume the sea level visual range to be 15 km and the ozone distribution to be representative of midlatitude summer conditions. In this example, the radiosonde data consists of 21 levels and only the following parameters are given: altitude (km), pressure (mb), ambient temperature (°C), and dew point temperature (°C).

The set up cards for the above problem are as follows:

```
**7**1**2**0**0**1**0**0**2*21
*****0.000**1015.000****24.4***21.4
      0.136  1000.000      22.0    19.4
      0.560   950.000      17.8    16.1
```

```
      1.080     892.000      14.8    11.9
      1.526     850.000      12.8     5.8
      1.650     832.000      12.8    -6.2
      2.270     775.000      11.8   -18.2
      3.140     700.000       7.2   -20.8
      5.820     500.000     -10.1   -28.1
      5.990     488.000     -11.5   -27.5
      7.510     400.000     -19.5   -31.5
      8.720     338.000     -28.5   -41.5
      9.180     318.000     -32.7   -39.7
      9.590     300.000     -35.3   -43.3
      9.720     294.000     -34.7   -42.7
     10.020     281.000     -38.7   -45.7
     10.830     250.000     -44.7   -50.0
     12.290     200.000     -57.1   -50.0
     13.600     161.000     -69.5   -50.0
     14.050     150.000     -71.1   -50.0
     16.450     100.000     -70.9   -50.0
*****0.210*****8.550****35.500****************************15.000
**1250.000**2500.000*****5.000
**2
**7  1  1  0  0  0  0  0  0 21
*****0.210**************************1.000**************15.000
**1250.000**2500.000*****5.000
**3
*****0.210**************************5.000**************15.000
**3
*****0.210*************************10.000**************15.000
***
```

Note that problems utilizing the standard model atmospheres must precede problems similar to Example 9 (see Section 5.3).

6.10 Typical Output from LOWTRAN 3

The output for a problem similar to Example 3 (Section 6.3) is given in Table 1. The parameters defining the atmospheric path, model atmospheres and frequency range will first be printed out. Following the heading HORIZONTAL PROFILES there are 12 columns. The first column gives a running integer associated with each level (level indicator). The second column gives the level altitude in km. The next 8 columns give the equivalent absorber amounts per km for the

following absorbing species: water vapor, uniformly mixed gases, ozone, nitrogen continuum, water vapor continuum, molecular scattering, aerosol extinction, and UV ozone, respectively. The last two columns give the mean refractive index modulus from that level to the level above and the refractive index modulus (multiplied by 10^6) at that level.

A heading VERTICAL PROFILES is then printed followed by 15 columns. The first and second columns give the integer associated with the levels traversed by the path and the height of the level. Then follow 8 columns which give the integrated equivalent absorber amounts from the initial altitude to the level above (in the same order as indicated above). The next 4 columns are labelled PSI, PHI, BETA, and THETA, and correspond to the angles similar to ψ, ϕ, β, and θ given in Figure 3 (Section 4.2). Columns PSI and BETA give the accumulated values of ψ and β to the level above. Columns THETA and PHI give the local zenith angle θ_i corresponding to that level and the angle of arrival at the level above, respectively. The accumulated slant range is printed out in the last column under RANGE.

The total equivalent absorber amounts for each absorber species are then summarized below in their appropriate units.

A transmittance table, containing 12 columns, now follows. The first 3 columns give the frequency (cm^{-1}), wavelength (microns), and total transmittance. The next 7 columns show the individual transmittance due to water vapor, uniformly mixed gases, ozone, nitrogen (4 μm) continuum, water vapor (10 μm) continuum, molecular scattering, and aerosol extinction. The last 2 columns give the absorption due to aerosols and the cumulative total integrated absorption. The latter quantity can be used to determine the average transmittance over any given spectral interval within the spectral range covered by the calculation. Finally, the total integrated absorption from V1 to V2 is printed out (units are cm^{-1}) together with the average transmittance over the band.

7. LIMITATION AND COMMENTS

It should be remembered that the transmittance values obtained from LOWTRAN 3 are at a spectral resolution of 20 cm^{-1}, although the output can be obtained at 5 cm^{-1} intervals.

The program will round off input frequencies to the nearest frequency at which spectral data are given.

The overall accuracy in transmittance, which this technique provides, is better than 10 percent. The largest errors may occur in the distant wings of strongly absorbing bands in regions where such bands overlap appreciably.

Table 1. Typical Output From LOWTRAN 3

```
          5    1    2   -0
H1= 2.56 [illegible] ... DEG, VIS= 0.0
H1= 2.50 [illegible] ... 1.1531 DEG, VIS=
          2.500     8.500     65.000     14.157     0.000
     2350.000   2450.000     5.000

     SLANT PATH ... ALTITUDES ... H1 = 2.500 KM H2 = 8.500 KM, AT AN ANGLE = 65.000 DEGREES

          [illegible] ... SUMMER ... WINTER

               [illegible] ... VISUAL RANGE

     [illegible] ... 2450.0 CM-1 FOR DV = 5.0 CM-1
```

HORIZONTAL PROFILES

1	0.0	[illegible]E-01	[illegible]+03	[illegible]E-01	9.753E-01	7.660E-06	1.062E+00	1.030E+00	1.313E-03	2.853E-04	4.053E+02
2	1.0	[illegible]E-01	[illegible]	1.814E-03	5.665E-01	5.951E-06	9.234E-01	4.330E-01	1.313E-03	2.506E-04	4.553E+02
3	2.0	7.527E-02	5.474E+01	1.764E-03	5.143E-01	4.513E-06	9.199E-01	1.944E+01	1.313E-03	2.213E-04	4.355E+02
4	3.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	4.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	5.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	6.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	7.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	8.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10	9.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11	10.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12	11.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13	12.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
14	13.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
15	14.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
16	15.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
17	16.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
18	17.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
19	18.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
20	19.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
21	20.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
22	21.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
23	22.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
24	23.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
25	24.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
26	25.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
27	30.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
28	35.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
29	40.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
30	45.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
31	50.0	7.590E-11	2.714E-05	1.079E-05	2.556E-07	1.783E-12	5.465E-04	3.909E-06	2.937E-06	9.125E-03	3.709E+01
32	70.0	1.556E-13	2.642E-08	[illegible]	1.473E-04	[illegible]	4.603E-05	1.062E-09	4.513E-06	5.389E-02	3.757E+02
33	100.0	1.498E-15	[illegible]E-12	[illegible]E-12	1.060E-13	1.442E-19	3.450E-07	5.961E-12	2.007E-09	5.355E-11	1.107E-05

VERTICAL PROFILES

										PSI	PHI	BETA	THETA	RANGE
3	2.5	8.594E-02	[illegible]E-01	2.057E-03	5.097E-01	3.778E-06	8.842E-01	1.181E-01	2.346E-03	.0000	115.0097	.3097	65.0000	1.2
4	3.5	1.517E-01	1.871E+00	6.155E-03	1.357E+00	8.550E-06	2.503E+00	2.576E-01	7.288E-03	.0031	115.0253	.3290	64.9936	3.5
5	4.5	1.747E-01	2.828E+00	1.073E-02	2.027E+00	1.070E-03	3.944E+00	3.443E-01	1.227E-02	.0057	115.0425	.3482	64.9757	5.9
6	5.5	2.127E-01	3.604E+00	1.426E-02	2.551E+00	1.156E-03	5.233E+00	4.077E-01	1.756E-02	.0080	115.0595	.3575	64.9597	8.3
7	6.5	2.213E-01	4.229E+00	1.898E-02	2.950E+00	1.193E-03	6.378E+00	4.507E-01	2.410E-02	.0101	115.0767	.3960	64.9426	10.6
8	7.5	2.234E-01	4.724E+00	2.502E-02	3.276E+00	1.205E-03	7.302E+00	5.005E-01	3.232E-02	.0120	115.0945	.1060	64.9253	13.0
9	8.5	2.244E-01	4.934E+00	3.079E-02	3.404E+00	1.207E-03	7.852E+00	5.336E-01	3.865E-02	.0134	115.1022	.1155	64.9074	14.2

EQUIVALENT SEA LEVEL ABSORBER AMOUNTS

	WATER VAPOUR GM CM-2	CO2 ETC. KM	OZONE ATM CM	NITROGEN (CONT) KM	H2O (CONT) GM CM-2	MOL. SCAT KM	AEROSOL KM	OZONE (U-V) ATM CM
[illegible]	2.244E-01	4.234E+00	2.474E-02	3.405E+00	1.207E-03	7.852E+00	5.336E-01	3.865E-02

TRANSMITTANCE TABLE

FREQ CM-1	WAVELENGTH MICRONS	TOTAL TRANS	H2O TRANS	CO2+ TRANS	OZONE TRANS	N2 CONT TRANS	H2O CONT TRANS	MOL SCAT TRANS	AEROSOL TRANS	AEROSOL ABS	INTEGRATED ABSORPTION
2350	4.2553	0.0006	.9965	0.0000	1.0000	.9575	1.0000	1.0000	.3907	.0311	2.55
2355	4.2463	0.0006	.9970	0.0000	1.0000	.9665	1.0000	1.0000	.3907	.0311	7.55
2360	4.2373	0.0002	.9975	0.0003	1.0000	.9735	1.0000	1.0000	.3907	.0311	12.55
2365	4.2283	0.0004	.9976	0.0001	1.0000	.9791	1.0000	1.0000	.3907	.0311	17.55
2370	4.2194	0.0006	.9977	0.0001	1.0000	.9827	1.0000	1.0000	.3907	.0310	22.55
2375	4.2105	0.0005	.9976	0.0002	1.0000	.9821	1.0000	1.0000	.3907	.0310	27.55
2380	4.2017	.0015	.9981	.0024	1.0000	.9950	1.0000	1.0000	.3907	.0310	32.49
2385	4.1929	.0290	.9986	.0613	1.0000	.9950	1.0000	1.0000	.3906	.0310	37.35
2390	4.1841	.1127	.9988	.1663	1.0000	.9927	1.0000	1.0000	.3906	.0310	41.77
2395	4.1754	.2594	1.0000	.3944	1.0000	.9791	1.0000	1.0000	.3906	.0310	45.49
2400	4.1667	.4615	1.0000	.5967	1.0000	.9804	1.0000	1.0000	.3906	.0310	48.11
2405	4.1580	.5734	1.0000	.4977	1.0000	.6927	1.0000	1.0000	.3905	.0310	50.22
2410	4.1494	.6735	1.0000	.9651	1.0000	.6937	1.0000	1.0000	.3905	.0310	51.95
2415	4.1408	.6939	1.0000	.4367	1.0000	.6965	1.0000	1.0000	.3905	.0310	53.41
2420	4.1322	.6765	1.0000	.9317	1.0000	.7054	1.0000	1.0000	.3905	.0319	54.95
2425	4.1237	.6942	1.0000	.9975	1.0000	.7136	1.0000	1.0000	.3905	.0305	55.67
2430	4.1152	.7035	1.0000	.9613	1.0000	.7236	1.0000	1.0000	.3905	.0303	57.35
2435	4.1068	.7090	1.0000	.9768	1.0000	.7350	1.0000	1.0000	.3905	.0303	59.41
2440	4.0984	.7144	1.0000	.9560	1.0000	.7447	1.0000	1.0000	.3905	.0303	60.51
2445	4.0900	.7237	1.0000	.9654	1.0000	.7552	1.0000	1.0000	.3905	.0303	62.21
2450	4.0816	.7351	1.0000	.9660	1.0000	.7705	1.0000	1.0000	.3905	.0304	62.97

INTEGRATED ABSORPTION FROM 2350 TO 2450 CM-1 = 62.97
-0

The reason for this error is twofold. First, a unique spectral curve in Figures 16 to 18, McClatchey et al,[2] is based on a single absorber parameter and cannot be defined for a wide range of atmospheric paths without some loss in accuracy.

Secondly, the transmittance in the window regions between strong bands generally lies in the weak line approximation region, where the transmittance is a function of the quantity of absorber present and not of the product of absorber amount and pressure. The one-dimensional prediction scheme presented in this report is not accurate for such conditions, which in general give transmittance values greater than 0.99. The digitized data were obtained for conditions representative of moderate atmospheric paths and will tend to overestimate the transmittance for very long paths and underestimate the transmittance for very short paths, in the spectral regions described above.

As the transmittance approaches 1.0, the percentage error in transmittance decreases toward zero but the uncertainty in the absorptance (or emittance) increases greatly.

Because of the nature of the program - which uses a layered atmosphere - errors can be introduced into the refraction calculation, since we assume each layer to have a mean refractive index associated with it. This is particularly true for a long path in one layer near ground level where one would expect refraction to be a maximum. But in fact, for such a condition the program may indicate no refraction at all. If problems like these are encountered, the number of levels must be increased in the altitude region of interest.

The effect of wavelength on refraction has been included (see Section 4.3). When a particular problem is set up for a frequency range V1 to V2, however, the average frequency is used in the refractive index calculation. If the reader is using LOWTRAN 3 for trajectory analysis where wavelength dependence of refractive index may be important, it is recommended that dummy values for V1 and V2 be used such that the average frequency corresponds to the frequency of interest.

If LOWTRAN 3 is to be used for trajectory analysis, it is recommended that the number of levels in the model atmospheres be increased substantially between the altitudes of interest. The computer program (with 34 levels) will tend to underestimate the refraction of the atmosphere by as much as 20 percent for the worst case (that is, a 90° path to space from sea level).

If LOWTRAN 3 is not being used for problems similar to Examples 6 and 7 it is recommended that the subroutine ANGL be removed from the program, thereby reducing the size of the card deck by approximately one-third.

Some examples of transmittance spectra obtained from LOWTRAN 3 are presented in Figures 5 through 11. From Figure 5 one can see the separate contributions to the total transmittance due to the various absorbing gases, molecular

scattering and aerosol attenuation. The other figures show the variation of atmospheric transmittance with (1) model atmosphere for fixed paths, (2) altitude and path for a fixed model atmosphere, and (3) range and zenith angle for a fixed altitude. In Figures 6 through 11 the aerosol attenuation is calculated on the basis of a 23 km sea level visual range.

In general, fairly good agreement has been found between experimental field measurements and LOWTRAN 3 predictions although a lack of accurate meteorological data (including visual range and actual aerosol characteristics) gives rise to some uncertainty.

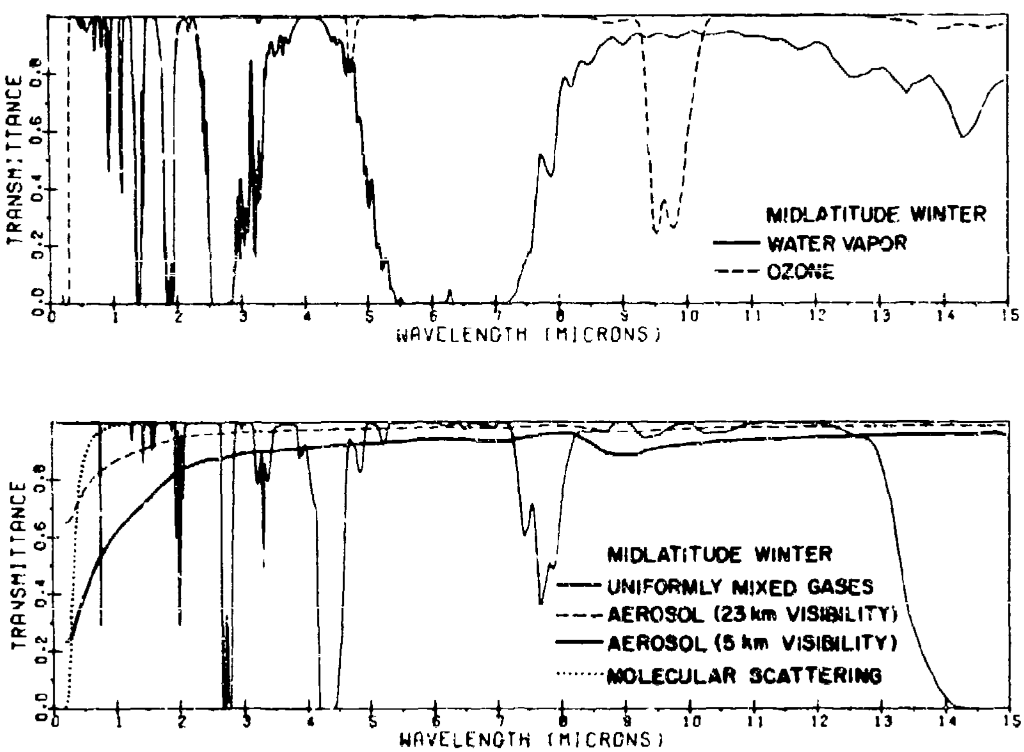


Figure 5. Vertical Path to Space From Sea Level for the Midlatitude Winter Model Atmosphere Showing the Separate Contributions to the Total Transmittance

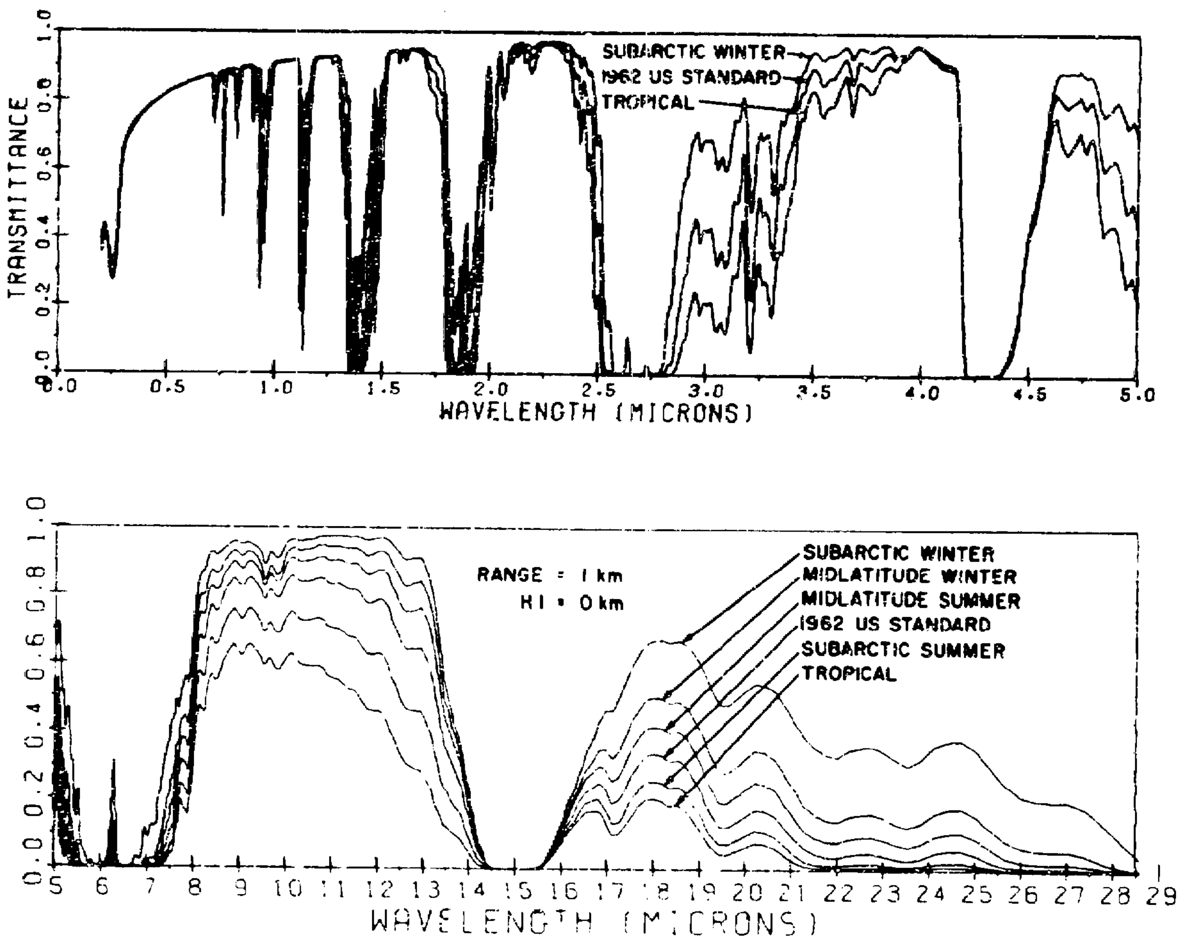


Figure 6. Atmospheric Transmittance for a 1 km Path at Sea Level for Six Model Atmospheres

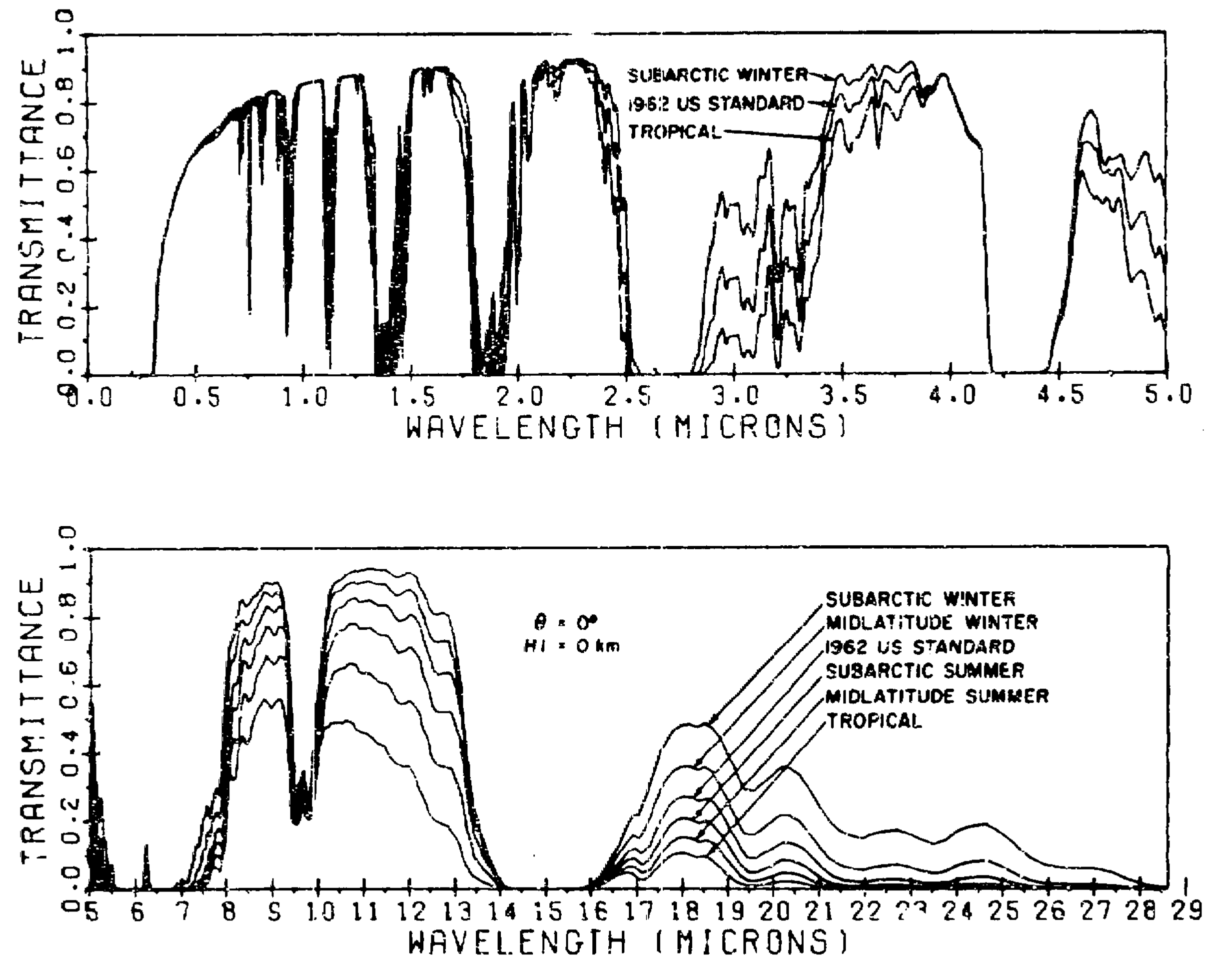


Figure 7. Atmospheric Transmittance for a Vertical Path to Space From Sea Level for Six Model Atmospheres

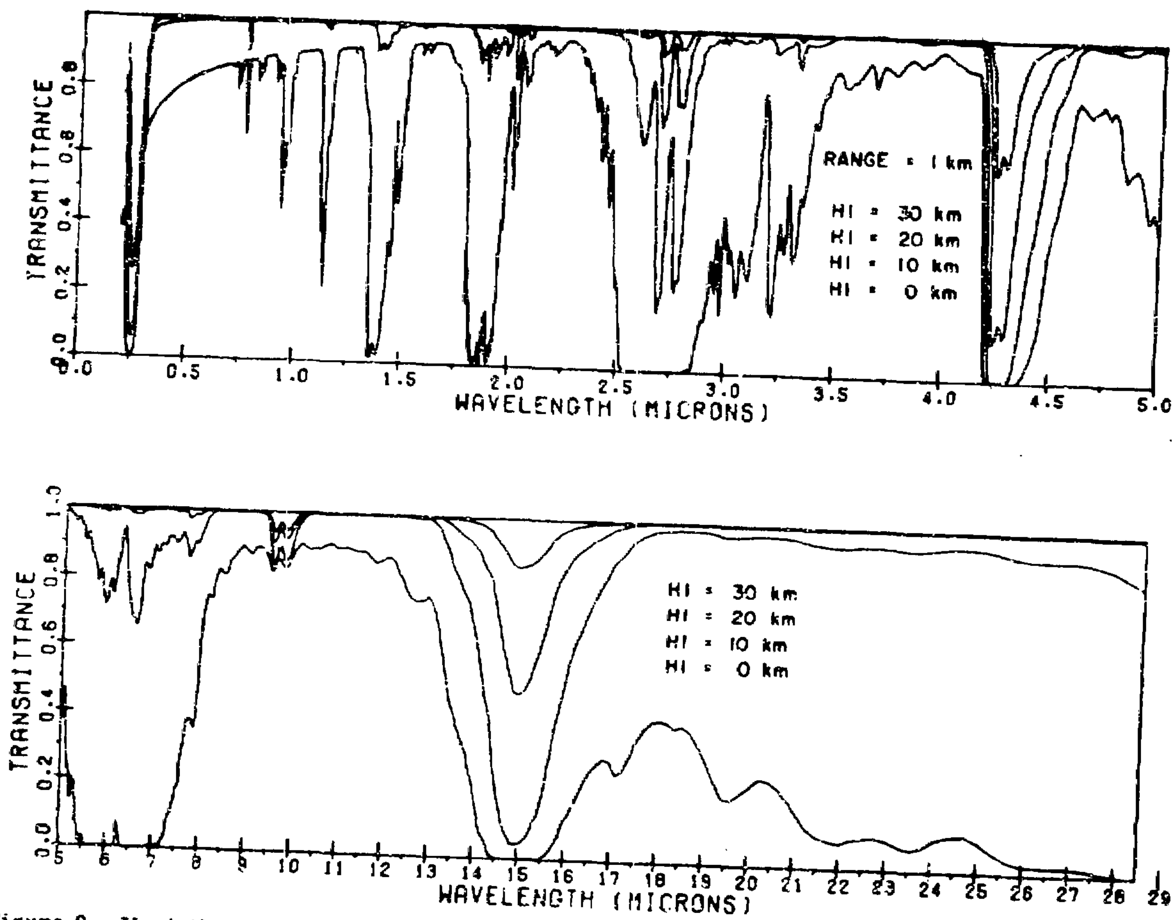


Figure 8. Variation of Transmittance With Altitude for a 1 km Path for the 1962 U.S. Standard Atmosphere

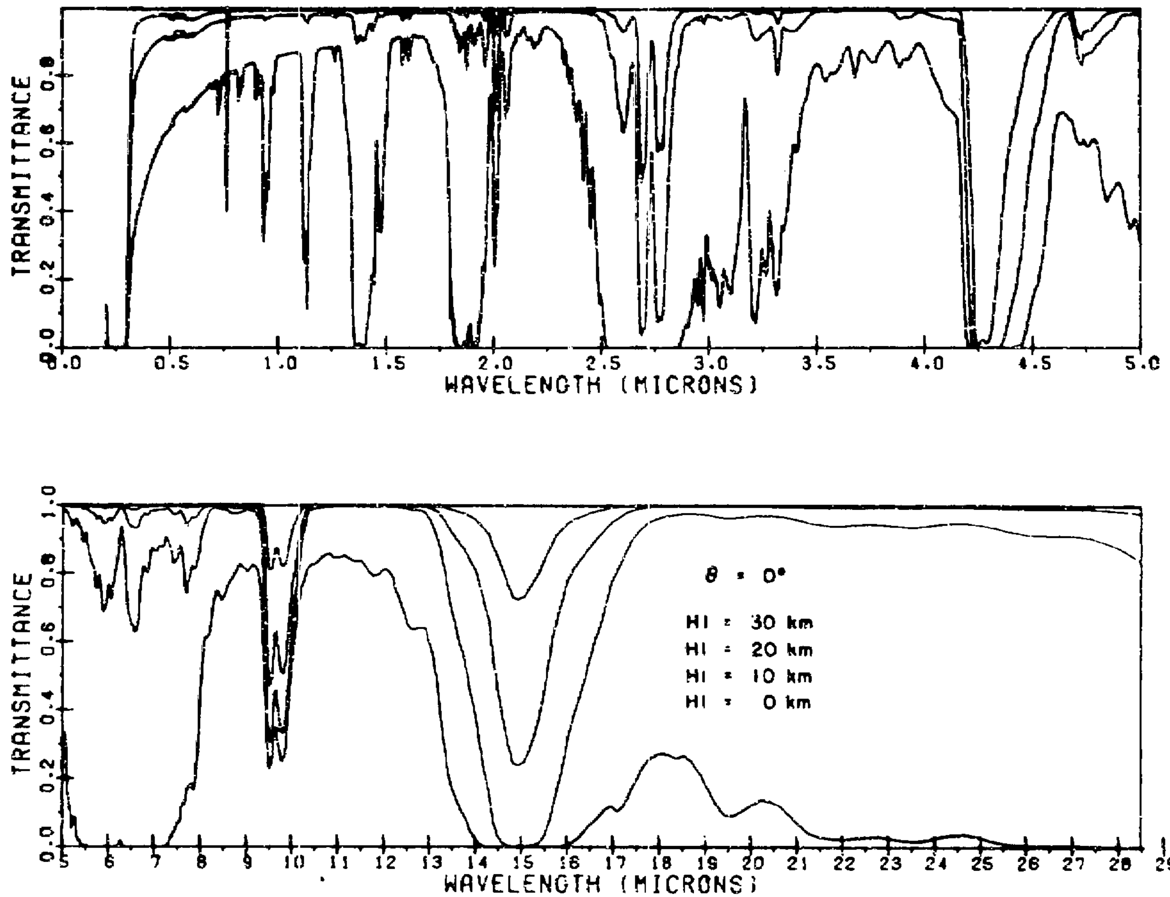


Figure 9. Variation of Transmittance With Altitude for a Vertical Path to Space for the 1962 U.S. Standard Atmosphere

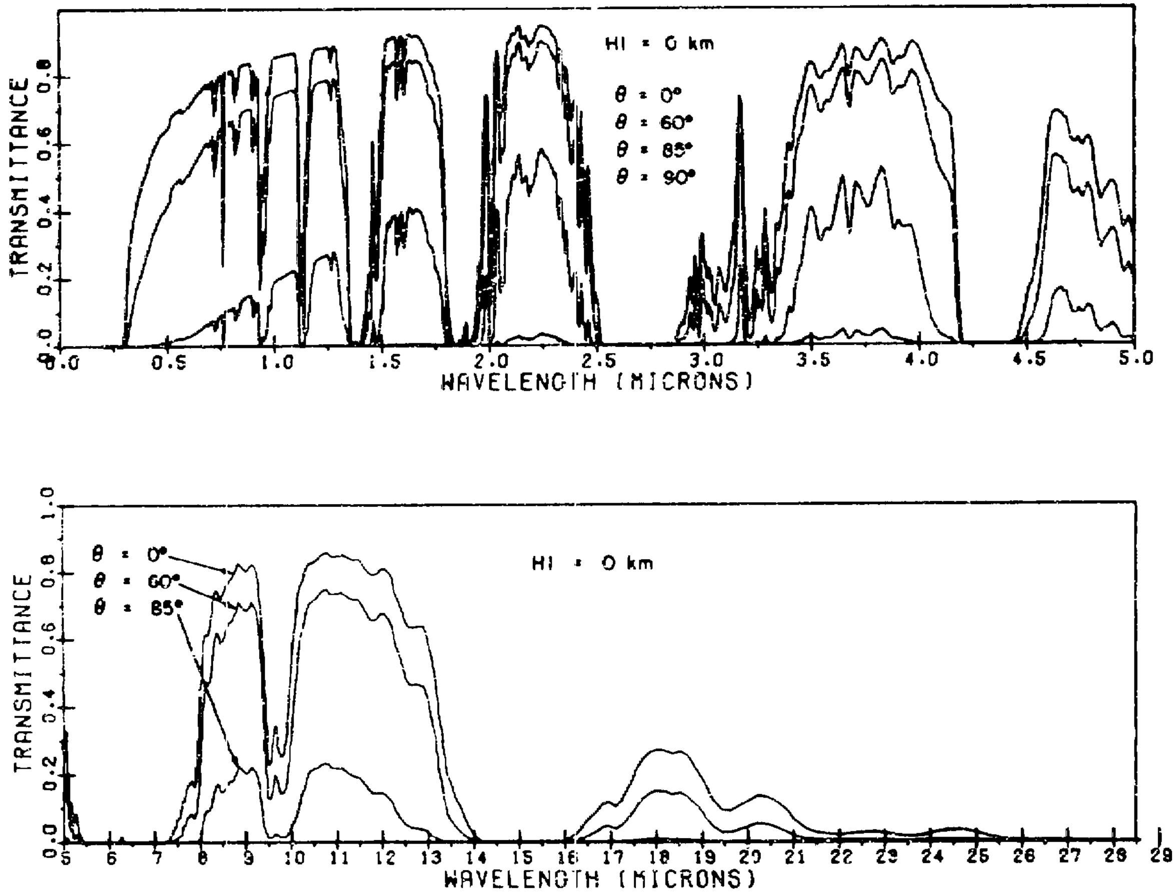


Figure 10. Variation of Transmittance With Zenith Angle for a Path From Sea Level to Space for the 1962 U.S. Standard Atmosphere

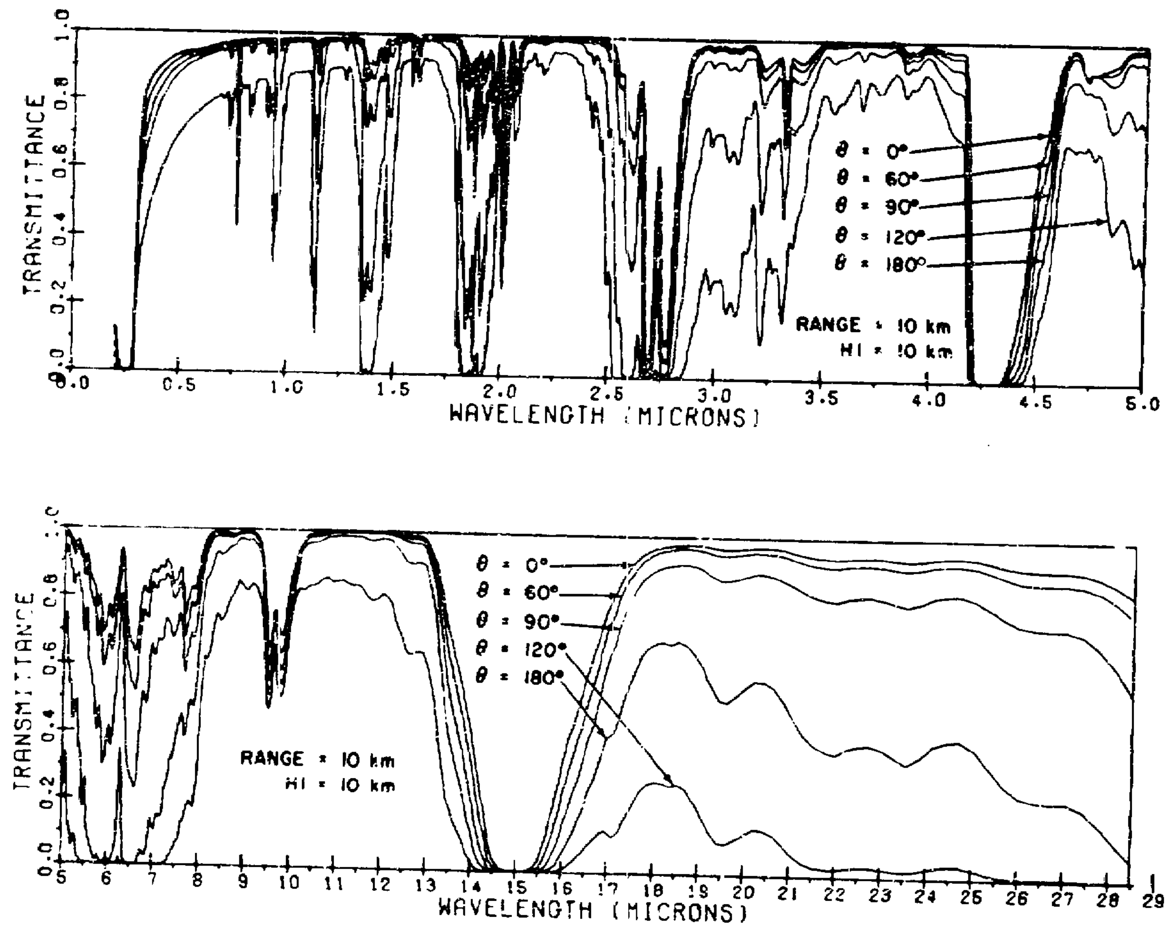


Figure 11. Variation of Transmittance With Zenith Angle for a Fixed 10 km Range at an Altitude of 10 km for the 1962 U.S. Standard Atmosphere

8. COMPARISONS OF LOWTRAN 3 PREDICTIONS WITH MEASUREMENTS

Figures 12 - 14 show some comparison of LOWTRAN 3 predictions with laboratory measurements of Howard, Burch and Williams[25] and Burch[26] for some important water vapor and carbon dioxide bands. It will be seen that the LOWTRAN 3 calculations agree closely both spectrally and in integrated absorption.

In Table 2 a comparison is made between five integrated absorption measurements of HBW[25] in the 2.7 μm H_2O band and those predicted using LOWTRAN 3. The measurements were chosen to be representative of conditions occurring in the first 50 km of the atmosphere.

Table 2. Comparison of LOWTRAN 3 Predicted and Measured Integrated Absorptions in the 2.7 μm Water Vapor Band

A = Integrated Absorption (3450 - 3850 cm^{-1})				
	Pressure (mb)	H_2O (pr cm)	$A_{LOWTRAN\ 3}$ (cm^{-1})	$A_{Meas.}$ (cm^{-1})
Case No. 1	1073	1.68	399	399
Case No. 2	997	0.21	382	374
Case No. 3	413	0.034	273	258
Case No. 4	413	0.017	133	131
Case No. 5	90.6	0.017	226	206

Figure 15 shows a transmittance spectrum measured by Gebbie et al[27] for a 1 nautical mile path over water, covering the 0.5 to 15 μm region. In the LOWTRAN 3 simulation of the spectrum the visual range was assumed to be 13 km which gives a transmittance of 60 percent at 0.6 μm. The effect of ozone absorption in the 10 μm region can be seen in the LOWTRAN 3 comparison, which shows a midlatitude winter concentration in one case and no ozone in the other. The no-ozone case appears to agree better with Gebbie's measurements.

25. Howard, J.N., Burch, D.L., and Williams, D. (1955) Near-Infrared Transmission Through Synthetic Atmospheres, AFCRL-TR-55-213, Geophysical Research Papers No. 40.

26. Burch, D.E., Gryvnak, D., Singleton, E.B., France, W.L., and Williams, D. (1962) Infrared Absorption by Carbon Dioxide, Water Vapor, and Minor Atmospheric Constituents, AFCRL-62-698.

27. Gebbie, H.A., Harding, W.R., Hilsum, C., Pryce, A.W., Roberts, V. (1951) Proc. Roy. Soc. 206A:87.

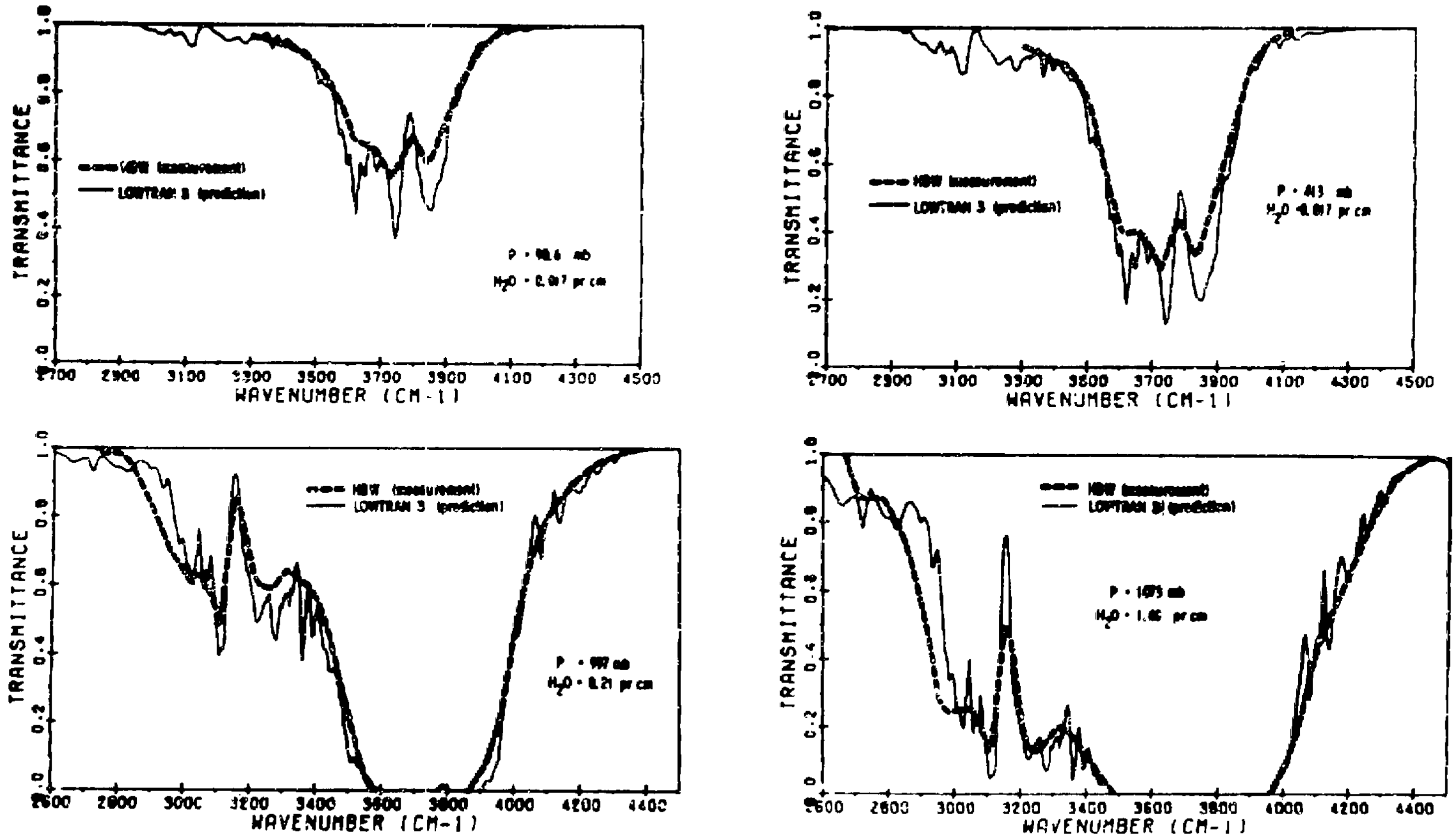


Figure 12. Comparison of LOWTRAN 3 Calculations and Howard, Burch and Williams Measurements for 2.7 µm Water Vapor Band

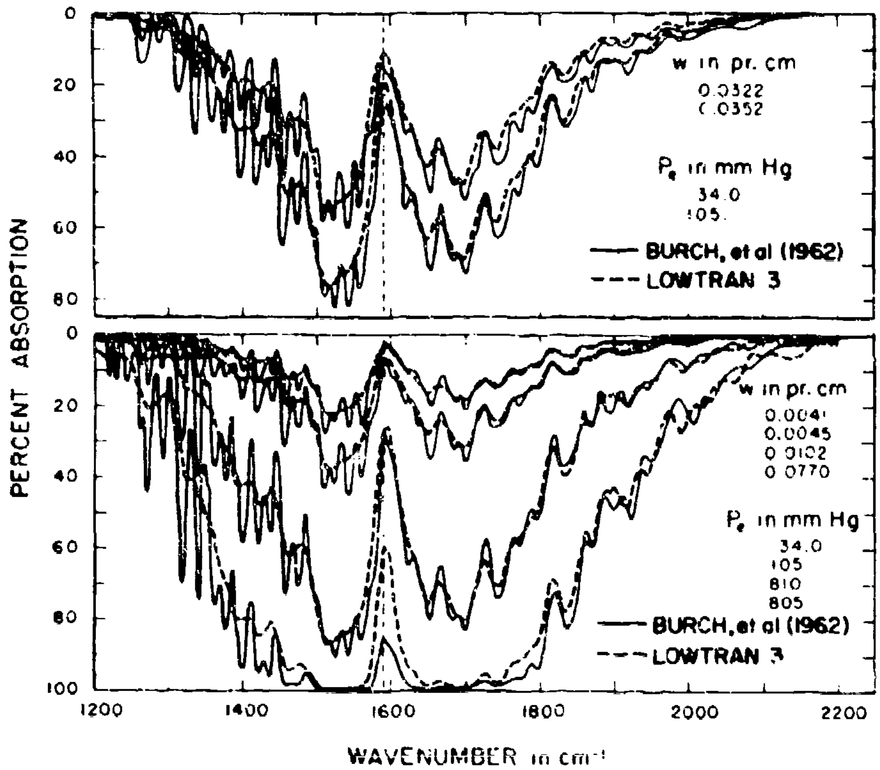


Figure 13. Representative Absorption Curves for the 6.3 μm H_2O Band. Spectral slit width equals approximately 6 cm^{-1}

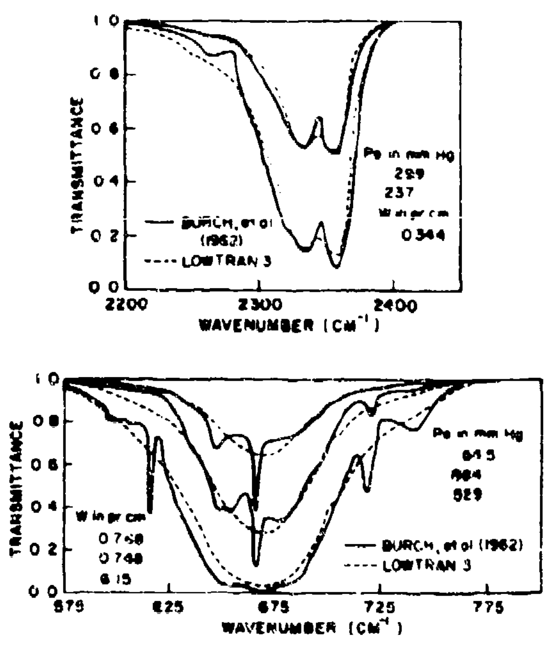
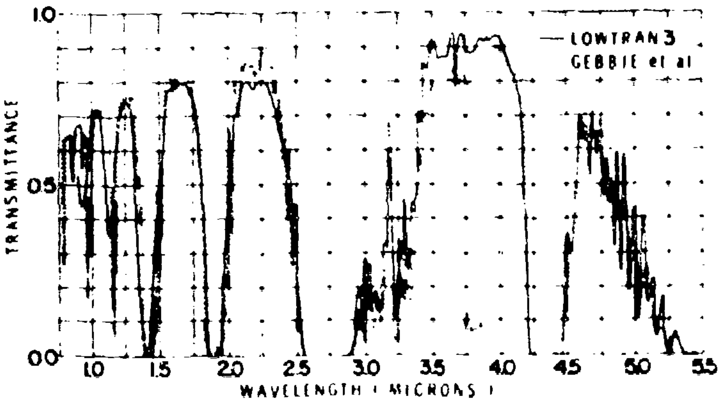


Figure 14. Comparison of LOWTRAN 3 Calculations and Measurements of Burch et al (1962) for CO_2 Bands at 4.3 μm and 15 μm



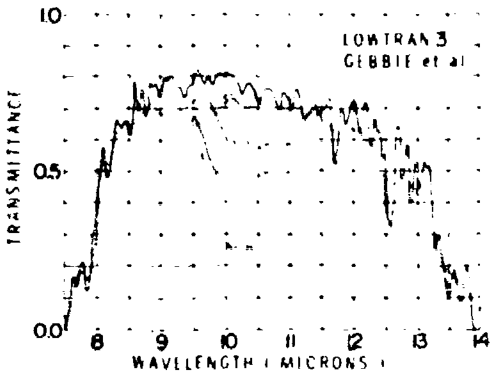


Figure 15. Atmospheric Transmittance for a 1 Nautical Mile Path (Water Content 1.7 pr cm)

Figures 16 - 22 show a series of measurements by Yates and Taylor[28] covering a wide spectral interval. The path lengths in these measurements are 0.3, 5.5, 16.25 and 27.7 km and were made at sea level (over water) with the exception of the 27.7 km path, which was at an altitude of 10,000 feet. No aerosol attenuation was used in simulating the 0.3 km path using LOWTRAN 3. The apparent wavelength shift at short wavelengths in Figure 16 is due to a calibration error in Yates and Taylor's measurements. The obvious discrepancy between prediction and measurement in the 10 μm is due to the fact that Yates and Taylor artificially set the transmittance level to be 100 percent in this window region (since they were unable to estimate the water vapor continuum contribution). The water vapor continuum given in LOWTRAN 3 extends from 7 to 15 μm. There is evidence that the effect of continuum absorption by H_2O extends to longer wavelengths (Bignell,[12] Burch et al[13]), and this is currently being investigated.

28. Yates, H.W., Taylor, J.H. (1960) Infrared Transmission of the Atmosphere, NR Report 5453, U.S. Naval Research Laboratory, Washington, D.C.

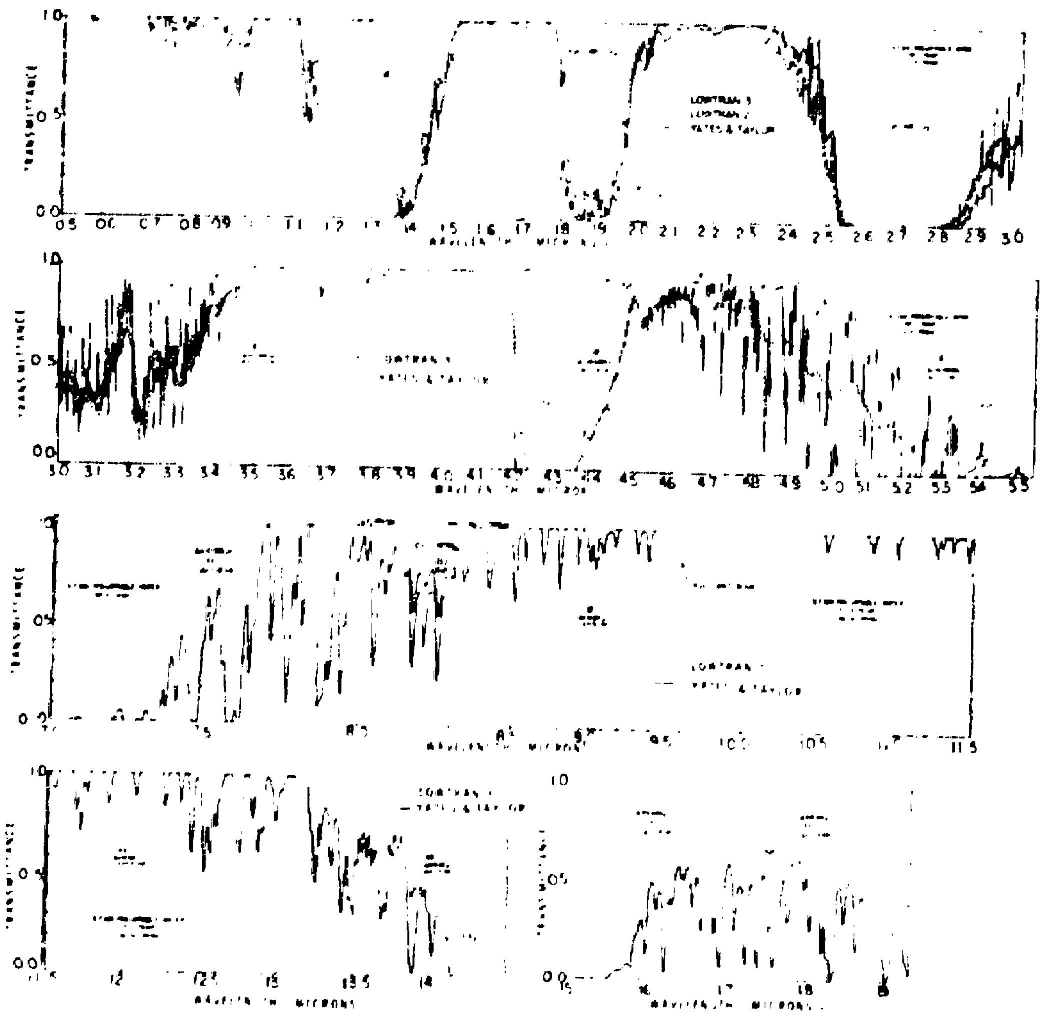
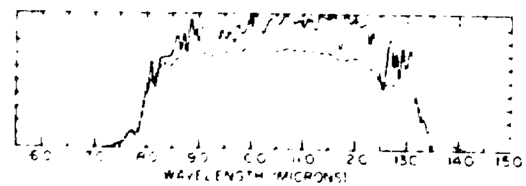
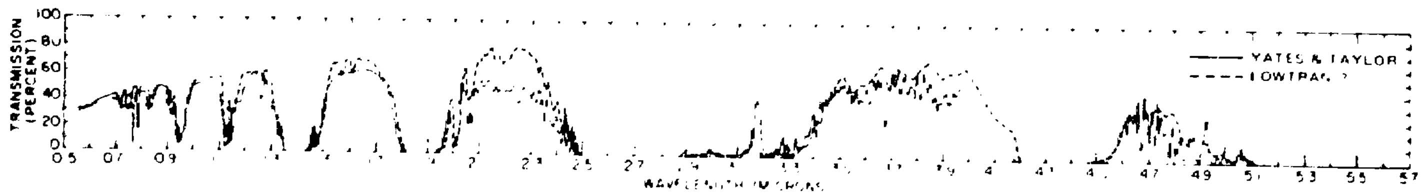


Figure 16. Atmospheric Transmittance Over a 0.3 km Path in the Chesapeake Bay Area

Path Length	5.5 km	Relative Humidity	66%
Time		H_2O in Path	2.2 cm
Temperature	38°F	Transmittance at 0.55 μm	40%
		LOWTRAN 3 visual range	23.5 km





Path Length	16.25 km	Relative Humidity	41%
Time		H_2O in Path	6.5 - 6.9 cm
Temperature	53 °F	Transmittance at 0.55 μm	20%
		LOWTRAN 3 visual range	51 km

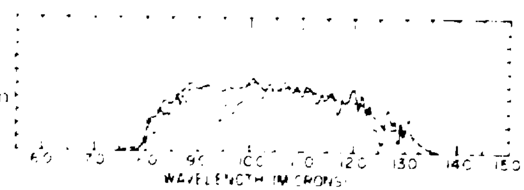
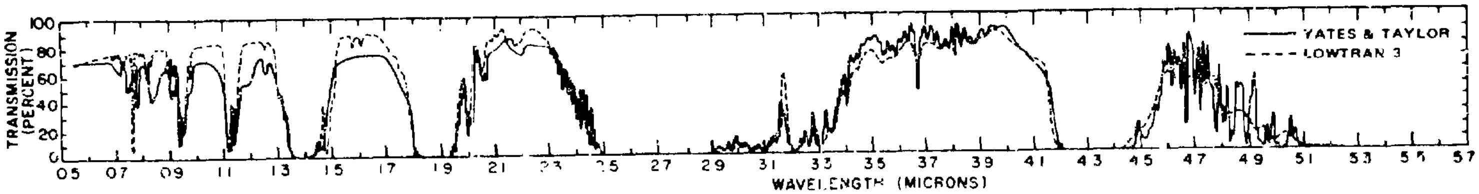
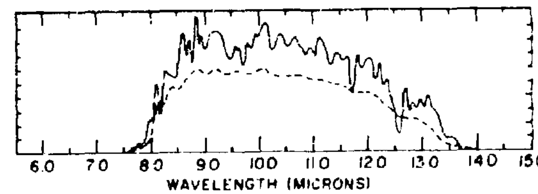


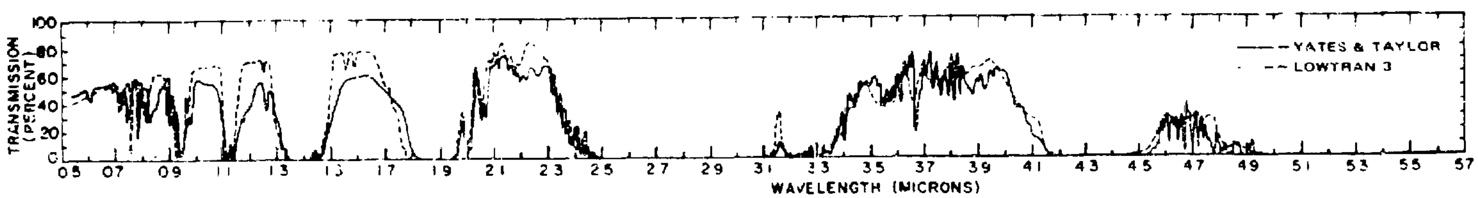
Figure 17. Comparison of LOWTRAN 3 Predictions With Atmospheric Transmittance Measurements Over (a) 5.5 km; (b) 16.25 km in the Chesapeake Bay Area on 19 April 1956

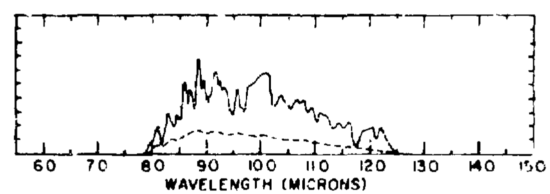




Path Length	5.5 km	Relative Humidity	51%
Time	2100 hr	H_2O in Path	4.18 cm
Temperature	64 °F	Transmittance at 0.55 μm	70%
		LOWTRAN 3 visual range	60 km

(a)

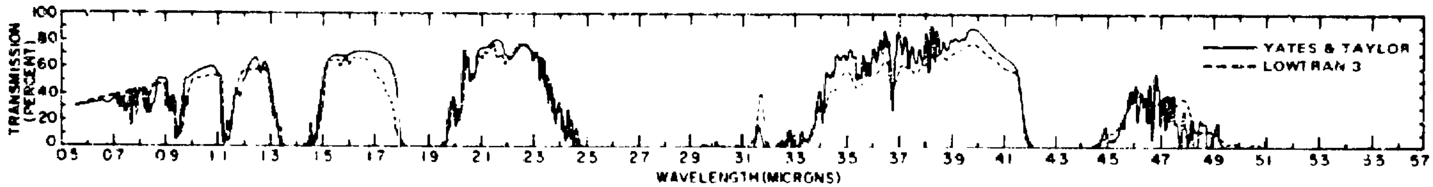




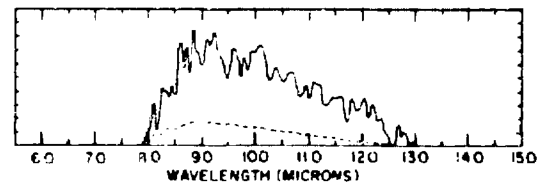
Path Length	16.25 km	Relative Humidity	53%
Time	1600 hr	H_2O in Path	15.1 cm
Temperature	69.7 °F	Transmittance at 0.55 μm	43%
		LOWTRAN 3 visual range	75 km

(b)

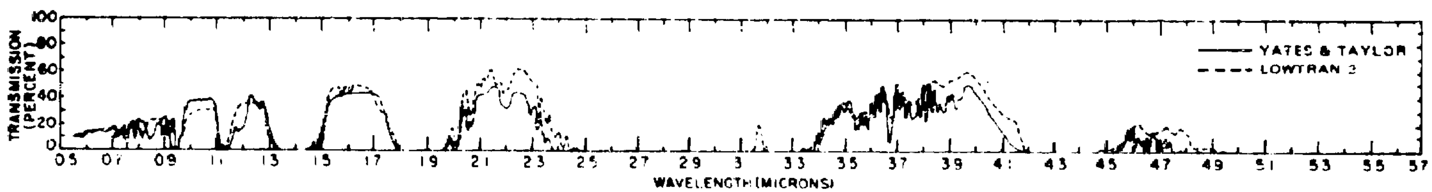
Figure 18. Comparison of LOWTRAN 3 Predictions With Atmospheric Transmittance Measurements Over: (a) 5.5 km; (b) 16.25 km in the Chesapeake Bay Area on 19 June 1956



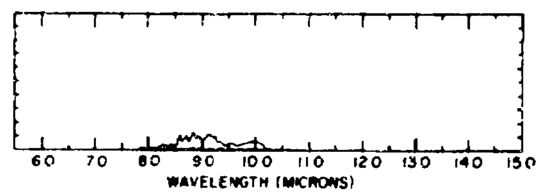
Path Length	5.5 km	Relative Humidity	73%
Time	1800 hr	H_2O in Path	3.4 cm
Temperature	78°F	Transmittance at 0.55 μm	30%
		LOWTRAN 3 visual range	18 km



(a)

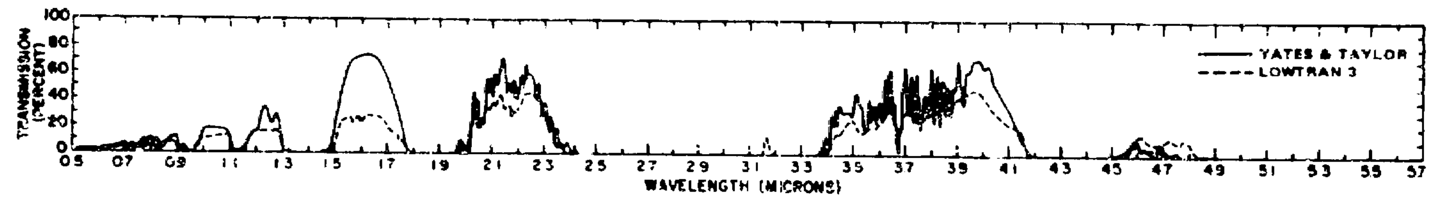


Path Length	16.25 km	Relative Humidity	82 %
Time	1100 hr	H_2O in Path	27.7 cm
Temperature	74°F	Transmittance at 0.55 μm	10%
		LOWTRAN 3 visual range	28 km



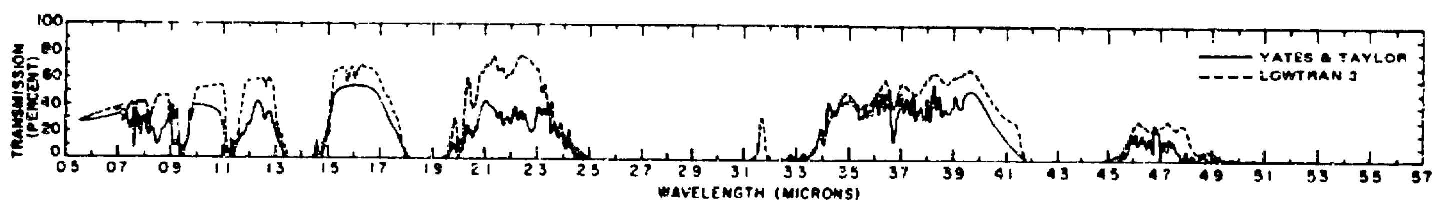
(b)

Figure 19. Comparison of LOWTRAN 3 Predictions With Atmospheric Transmittance Measurements Over: (a) 5.5 km; (b) 16.25 km in the Chesapeake Bay Area on 27 August 1956



Path Length	16.25 km	Relative Humidity	59%	LOWTRAN 3 visual range	16.2 km
Time	1900 hr	H_2O in Path	36 - 38 cm		
Temperature	87.5°F	Transmittance at 0.55 μm	2%		

Figure 20. Comparison of LOWTRAN 3 Predictions With Atmospheric Transmittance Measurements Over 16.25 km in the Chesapeake Bay Area on 16 June 1957



Path Length	27.7 km	Relative Humidity	100%
Altitude	10,000 ft	H_2O in Path	20 cm
Time	1130 hr	Transmittance at 0.55 μm	26.5%
Temperature	43°F	LOWTRAN 3 visual range	50 km

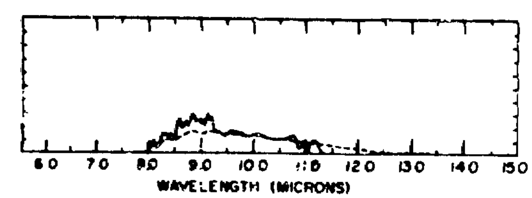
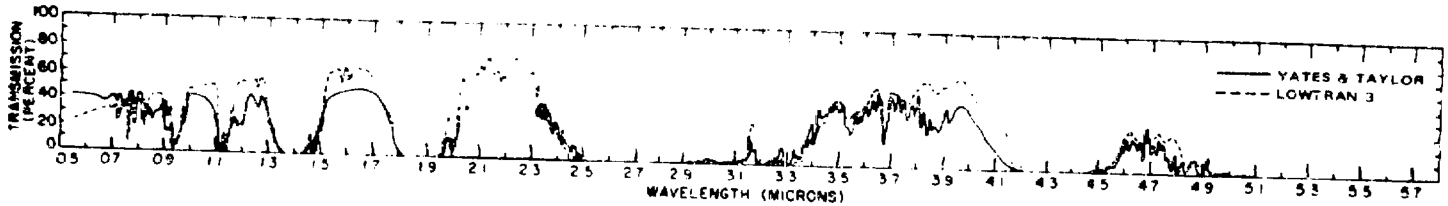


Figure 21. Comparison of LOWTRAN 3 Predictions With Atmospheric Transmittance Measurements Over 27.7 km in the Hawaiian Islands on 1 September 1957



Path Length	27.7 km		
Altitude	10,000 ft	H_2O in Path	8 - 13 cm
Time	2300 hr	Transmittance at 0.55 μm	41%

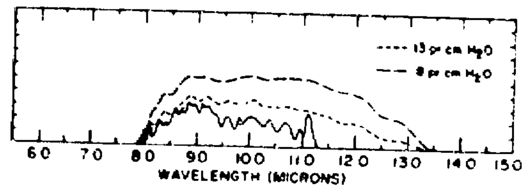


Figure 22. Comparison of LOWTRAN 3 Predictions With Atmospheric Transmittance Measurements Over 27.7 km in the Hawaiian Islands 6 - 7 September 1957

In Figures 17 - 22 the transmittance values at 0.55 µm given by Yates and Taylor were used to estimate the visual range used in the LOWTRAN 3 simulations. In some cases (see Figure 22 for example), choosing a lower visual range gives far better agreement between the measurements and LOWTRAN 3 predictions. Generally, the predictions and measurements disagree most in the 10 µm region, where it is extremely difficult to obtain absolute transmittance values from long path measurements in the atmosphere. Because of the importance of the 10 µm window region in many applications, it is strongly suggested that future field measurements of this kind be carried out with extreme care, in order to obtain reliable atmospheric transmittance data against which a model such as LOWTRAN 3 can be tested.

It is also apparent that there are some inconsistencies in the measurements shown in Figures 16 - 22 which are the cause of some apparent deviations between the LOWTRAN 3 predictions, and the measurements.

Figures 23 - 26 show some more recent sea level measurements made by Ashley et al[29] (General Dynamics). These measurements have been made at somewhat higher resolution (~ 4 cm^{-1}) and cover the spectral regions 1.8 - 5.4 µm and 4.8 - 14 µm using two interferometers with different detectors. In Figures 23 and 24 the transmittance measurements were made over short and medium path lengths (that is, $\sim$ 0.045 km and 3.25 km) and covered the spectral region from 1.8 to 5.4 µm. A 1.3 km sea level path transmittance spectrum covering the 1.8 to 14 µm region is shown in Figure 25. In the latter spectrum the transmittance was normalized to unity in the 10 µm region. The anomalous spike shown at $\sim$ 13 µm was due to electrical noise. Figure 26 shows a long slant path measurement ($\sim$ 12 km) from 800 ft to 3187 ft altitude. Again the agreement between these measurements and LOWTRAN 3 predictions is good. The improvement of LOWTRAN 3 over LOWTRAN 2 in the 2 - 3.5 µm region can be seen from Figure 25.

Figure 27 shows three aircraft measurements made by Cumming et al[30] (CARDE) in the 2.7 µm region at an altitude of 13.7 km. The measurements were made over Florida using the sun as a radiation source.

In the LOWTRAN 3 predictions shown in Figure 27 the sensitivity of the transmittance to atmospheric conditions is indicated. For example the upper figure shows the transmittance obtained from LOWTRAN 3 using the tropical and 1962 U.S. Standard Atmospheres compared with the CARDE measurement. The second

---

29. Ashley, G.W., Gastineau, L., and Blay, D. (1973) Private Communication.

30. Cumming, C., Hawkins, G.R., McKinnon, D.J.G., Rollins, J., and Stephenson, W.R. (1965) Quantitative Atlas of Infrared Stratospheric Transmission in the 2.7 Micron Region, Canadian Armament Research and Development Establishment, CARDE T.R. 546/65, Project D46-38-01-19.

figure shows a LOWTRAN 3 comparison using the Tropical Model Atmosphere with and without aerosol attenuation. The latter curve appears to agree better with the measurement.

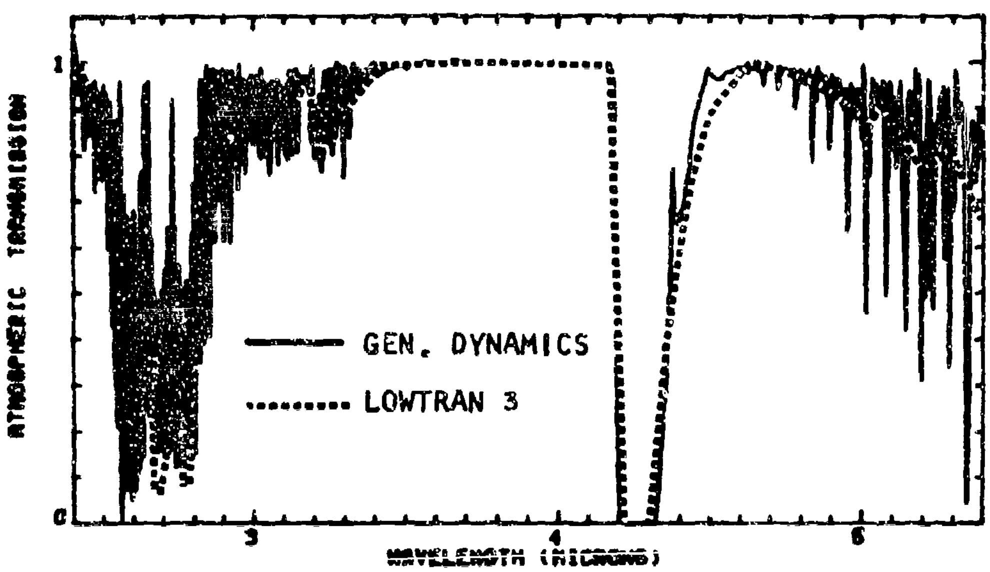


Figure 23. Comparison Between LOWTRAN 3 and General Dynamics Measurements 150 ft (45 m) Path at Sea Level (H_2O = 0.35 pr cm/km)

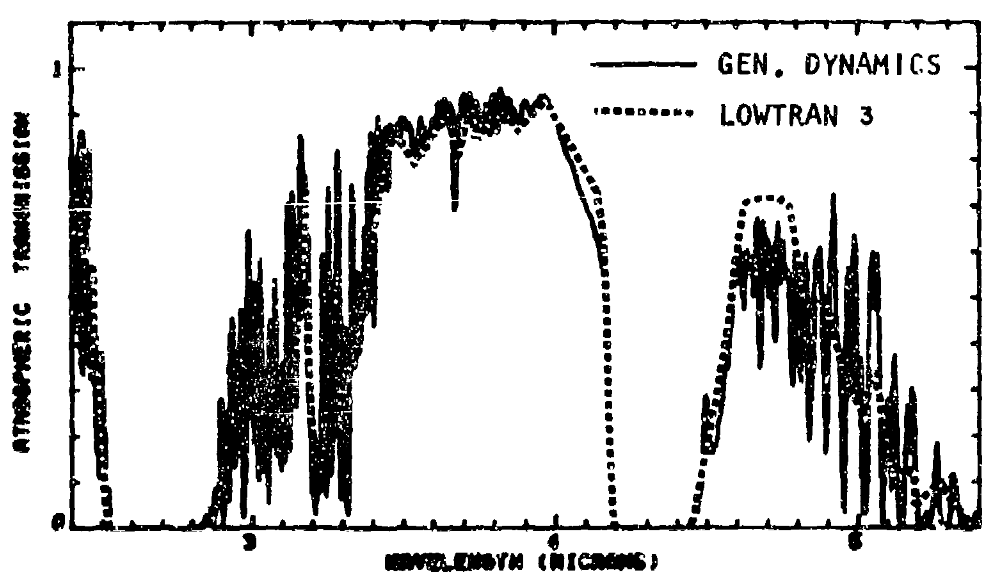


Figure 24. Comparison Betw ·n LOWTRAN 3 and General Dynamics Measurements; 10,679 ft (3.25 kn) Path at S · Level (H_2O = 0.35 pr cm/km)

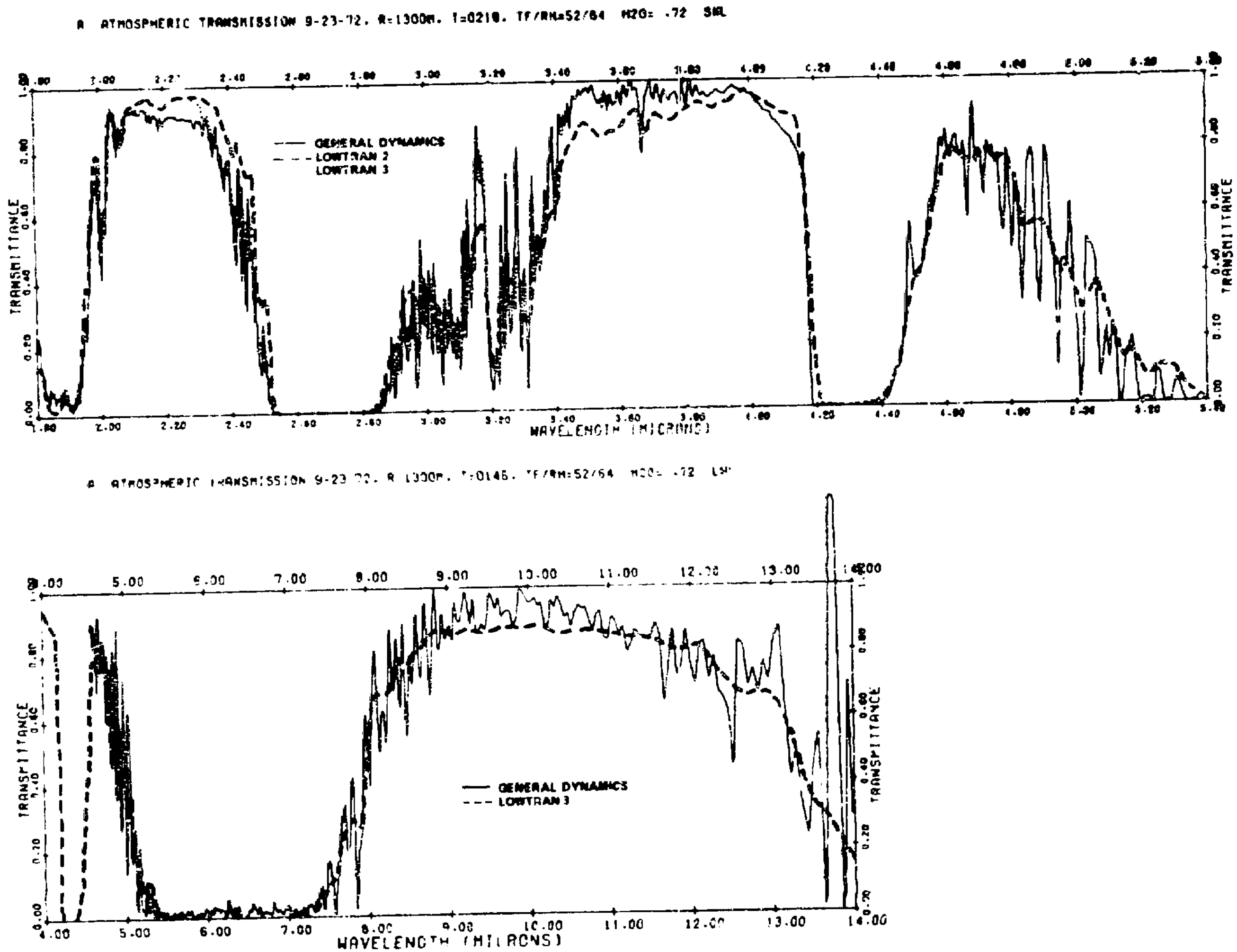


Figure 25. Comparison Between LOWTRAN 3, LOWTRAN 2, and General Dynamics Measurements; Range = 1.3 km at Sea Level (H_2O = 0.72 pr cm/km)

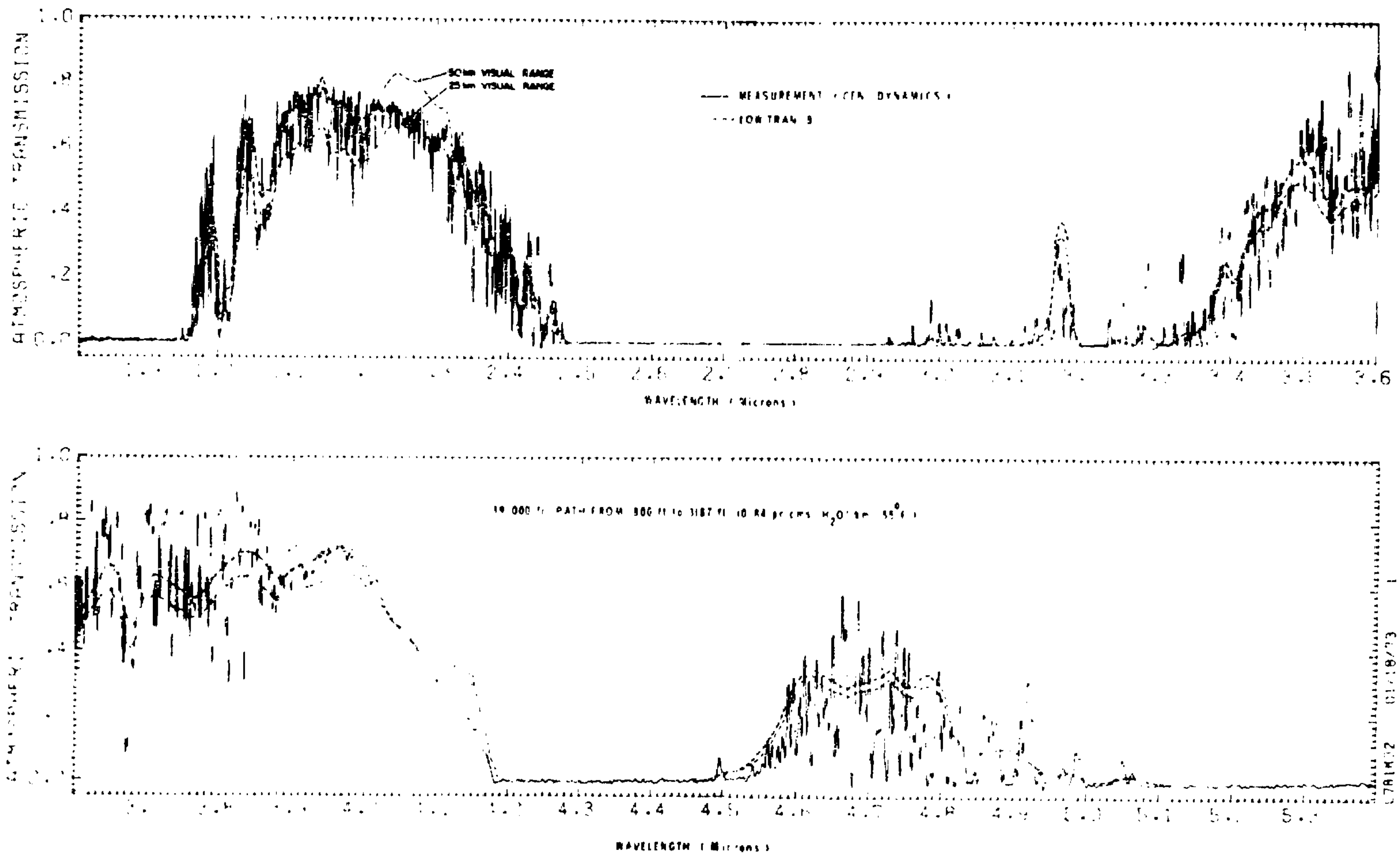


Figure 26. Comparison Between LOWTRAN 3 and General Dynamics Measurements; 39,000-ft path from 800 ft to 3187 ft (0.84 pr cm H_2O/km)

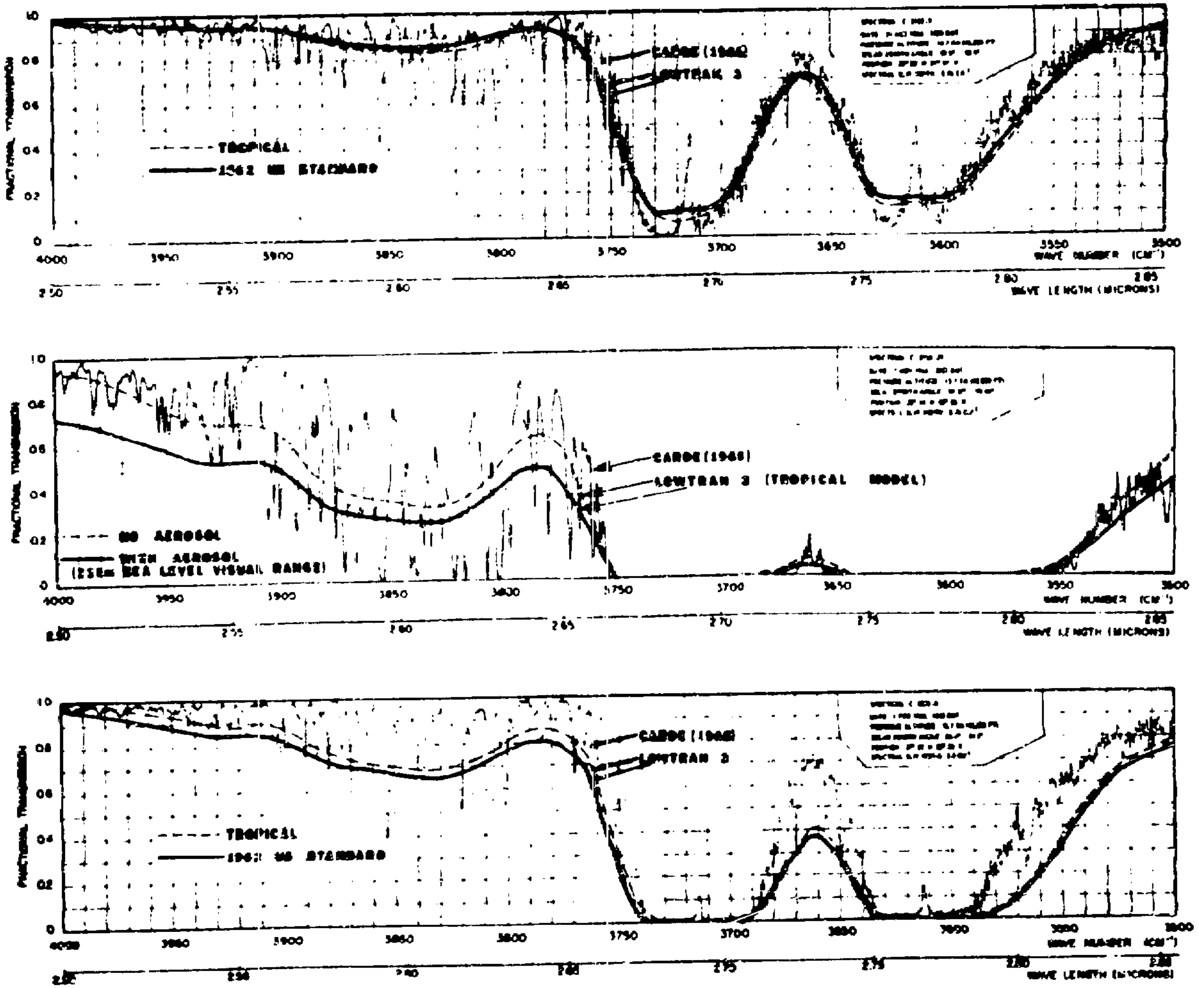


Figure 27. Comparison Between LOWTRAN 3 and CARDE (1965) Measurements Through an Atmospheric Slant Path

Figure 28 shows two atmospheric transmittance measurements made by Farmer et al[31] (EMI) for horizontal paths at 5.2 km altitude in the Bolivian Andes. The measurements were made over path lengths of 1.9 and 3.4 km and covered the 4 μm spectral region.

In general, LOWTRAN 3 predictions compare fairly well with available atmospheric transmittance measurements. Further laboratory studies will be conducted to determine more accurately the effect of continuum absorption by water vapor primarily in the 10 μm and 18 - 30 μm regions. It is hoped that further refined atmospheric transmittance measurements over long atmospheric paths will be made in the near future, with much attention payed to obtaining accurate absolute transmittance measurements in the window regions.

As more measurements become available, it is planned to update LOWTRAN. A version of the program which is also capable of predicting atmospheric "clear sky" and earth backgrounds will be published in the near future. Two examples of some typical radiance calculations using a modified LOWTRAN program are shown in Figure 29. Figure 29a gives the clear sky radiance for a vertical path from sea level to space for six model atmospheres and Figure 29b shows both the upward spectral radiance (as viewed from space) for a midlatitude winter model atmosphere and the downward radiance at sea level. The back body spectral radiance curve, superimposed on Figure 29b corresponds to a ground temperature of 272°K (assuming a ground emissivity of unity).

31. Farmer, C. B., Berry, P. J., and Lloyd, D. B. (1963) Atmospheric Transmission Measurements in the 3.5 to 5.5 Micron Band at 5200 Meters Altitude, EMI Electronics Limited, Hayes, Middlesex, England, Report No. DMP 1578.

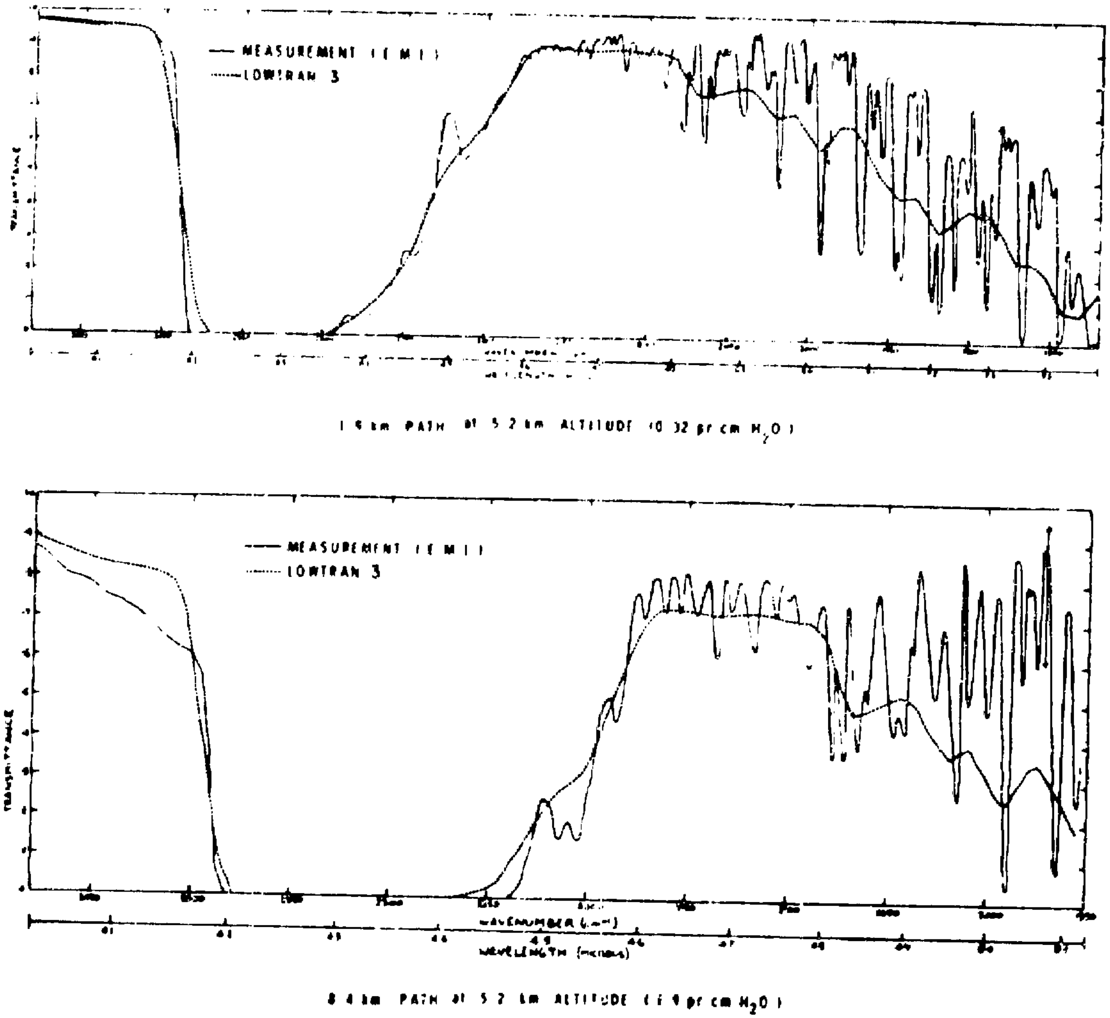


Figure 28. Comparison Between LOWTRAN 3 and EMI Measurements for a 1.9 km and 8.4 km Path

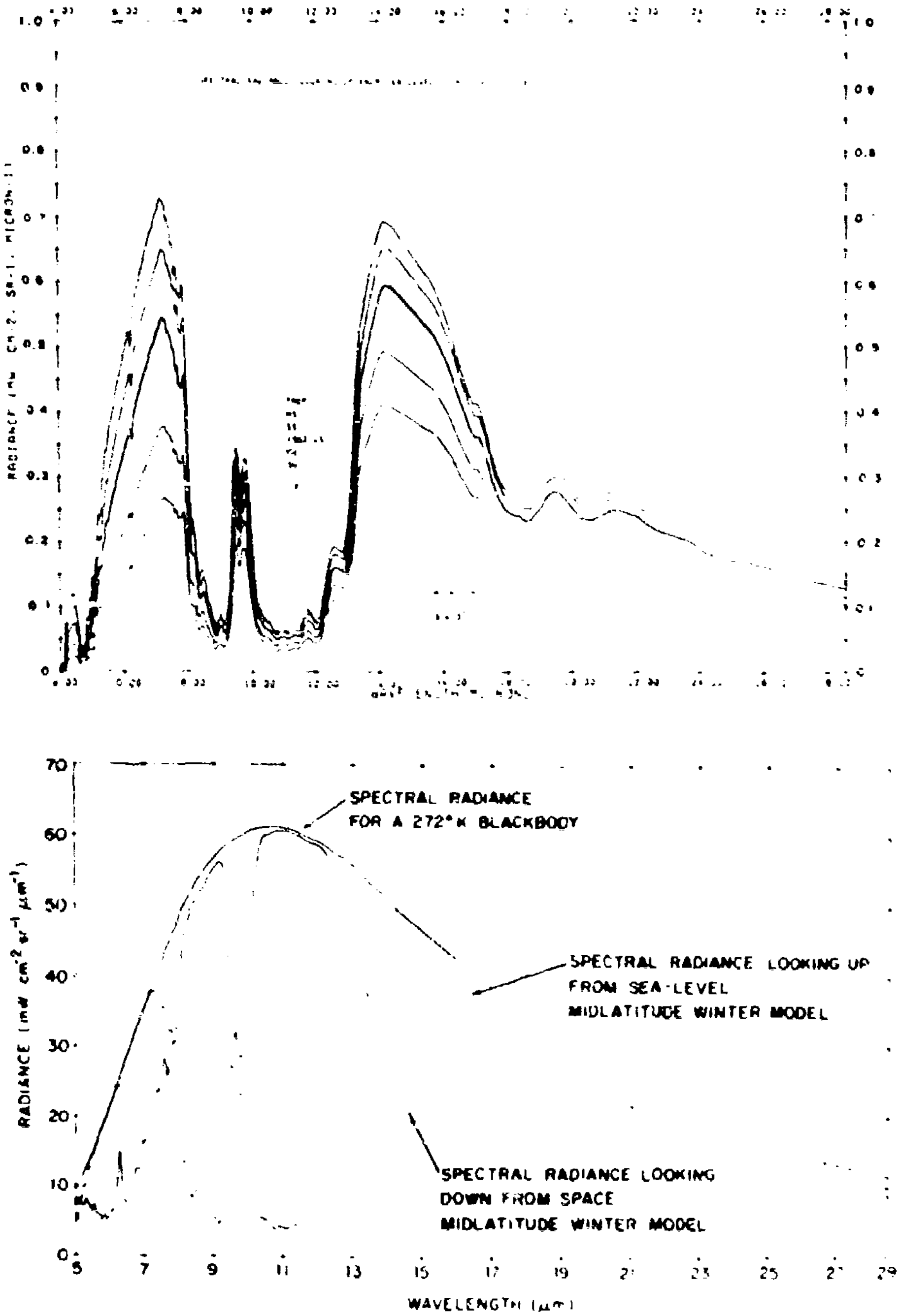


Figure 29. Two Examples of Some Typical Radiance Calculations Using a Modified LOWTRAN Program

References

1. Altshuler, T. L. (1961) Infrared Transmission and Background Radiation by Clear Atmospheres, GE Report 61 SD 199, AD-401923.

2. McClatchey, R. A., Fenn, R. W., Selby, J. E. A., Volz, F. E., and Garing, J. S. (1972) Optical Properties of the Atmosphere (Third Edition), AFCRL-72-0497.

3. Manley, O. P., Smith, H. J. P., Treve, Y. M., Carpenter, J. W., Degges, T. C., Doan, L. R. (1971) OPTIR II, AFCRL-71-0528 (Vol. 2 & 3)
   (1973) OPTIR III, AFCRL-TR-73-0217 and 0491
   (1974) OPTIR IIIB, AFCRL-TR-74-0319.

4. Selby, J. E. A., and McClatchey, R. A. (1972) Atmospheric Transmittance from 0.25 to 28.5 μm: Computer Code LOWTRAN 2, AFCRL-72-0745.

5. Valley, S. L., Ed. (1965) Handbook of Geophysics and Space Environments, AFCRL.

6. Sissenwine, N., Grantham, D. D., Salmela, H. A. (1968) Humidity Up to the Mesopause, AFCRL-68-0550.

7. Herring, W. S., and Borden, T. R. (1964) Ozone Observations Over North America, AFCRL-64-30, Vol. 2.

8. List, R. J. (1968) Smithsonian Meteorological Tables (6th revised edition), Smithsonian Institute Press, Washington.

9. Burch, D. E. (1970) Semi-Annual Technical Report: Investigation of the Absorption of Infrared Radiation by Atmospheric Gases, Aeronutronic Report U-4784 (31 Jan 71).

10. Burch, D. E., Gryvnak, D. A., and Pembroke, J. D. (1971) Philco Ford Corp., Aeronutronic Report U-4897, ASTIA (AD 882876).

11. McCoy, J. H., Rensch, D. B., and Long, R. K. (1969) Appl. Opt. 8:1471.

12. Bignell, K. J. (1970) Quart. J. Roy. Met. Soc. 96:409

13. Burch, D. E., Gryvnak, D. A., and Gates, F. J. (1974) Continuum Absorption by H_2O Between 330 and 825 cm^{-1}, AFCRL-TR-74-0377.

14. Reddy, S. R., and Cho, C. W. (1965) Canad. J. Physics 43:2331.

15. Shapiro, M. M., and Gush, H. P. (1966) Canad. J. Physics 44:949.

16. Penndorf, R. (1961) Research on Aerosol Scattering in the Infrared, Scientific Report No. 5, AFCRL-1044, Oct 1961.

17. Deirmendjian, D. (1964) Appl. Opt. 3:187.

18. Deirmendjian, D. (1969) Electromagnetic Scattering on Spherical Polydispersions, American Elsevier Pub. Co., N.Y.

19. Elterman, L. (1968) UV, Visible and IR Attenuation for Altitudes up to 50 km, AFCRL-68-0153.

20. Elterman, L. (1970) Vertical Attenuation Model with Eight Surface Meteorological Ranges 2 to 13 km, AFCRL-70-0200.

21. Volz, F. E. (1972) Appl. Opt. 11:755.

22. McClatchey, R. A., and Selby, J. E. A. (1974) Atmospheric Attenuation of Laser Radiation from 0.76 to 31.25 μm, AFCRL-TR-74-0003.

23. Middleton, W. E. K. (1952) Vision Through the Atmosphere, Univ. of Toronto Press.

24. Edlen, B. (1966) Metrologia 2:12.

25. Howard, J. N., Burch, D. L., and Williams, D. (1955) Near-Infrared Transmission Through Synthetic Atmospheres, AFCRL-TR-55-213, Geophysical Research Papers No. 40.

26. Burch, D. E., Gryvnak, D., Singleton, E. B., France, W. L., and Williams, D. (1962) Infrared Absorption by Carbon Dioxide, Water Vapor, and Minor Atmospheric Constituents, AFCRL-62-698.

27. Gebbie, H. A., Harding, W. R., Hilsum, C., Pryce, A. W., Roberts, V. (1951) Proc. Roy. Soc. 206A:87.

28. Yates, H. W., Taylor, J. H. (1960) Infrared Transmission of the Atmosphere, NR Report 5453, U. S. Naval Research Laboratory, Washington, D.C.

29. Ashley, G. W., Gastineau, L., and Blay, D. (1973) Private Communication.

30. Cumming, C., Hawkins, G. R., McKinnon, D. J. G., Rollins, J., and Stephenson, W. R. (1965) Quantitative Atlas of Infrared Stratospheric Transmission in the 2.7 Micron Region, Canadian Armament Research and Development Establishment, CARDE T. R. 546/65, Project D46-38-01-19.

31. Farmer, C. B., Berry, P. J., and Lloyd, D. B. (1963) Atmospheric Transmission Measurements in the 3.5 to 5.5 Micron Band at 5200 Meters Altitude, EMI Electronics Limited, Hayes, Middlesex, England, Report No. DMP 1578.

Appendix A

Listing of Program and Data

A listing of the Fortran program LOWTRAN 3 is given in Table A1 together with the two subroutines POINT and ANGL (see Appendix C for an explanation of subroutine ANGL). The input data for the program is given in Table A2. A general flow chart for the main program is presented in Appendix B, and definitions of the symbols used in the computer codes are summarized in Appendix D.

The subroutine POINT has a twofold purpose. When the subroutine is called for a given altitude X, it is used to determine the mean refractive index (1) in the layer between X and the level above, TX(9), and (2) in the layer between X and the level below, YN. In addition, an interpolation scheme is used to determine the effective absorber amounts per km at altitude X for each absorber. When the parameter IP is set equal to zero only the mean refractive index above and below altitude X is determined from POINT.

The subroutine ANGL is used solely for the purpose of calculating the initial zenith angle (θ_o or ANGL) by an iterative scheme taking into account refraction, given (1) the initial and final altitudes of the path (H1 and H2 respectively) and the angle subtended at the earth's center (β or BETA) by the trajectory, or (2) the initial altitude and tangent height (H1 and HMIN respectively). Examples of two typical problems involving the use of the subroutine ANGL are given in Sections 6.6 and 6.7. An explanation of the iteration scheme is given in Appendix C.

The changes necessary to update LOWTRAN 2 to LOWTRAN 3 are indicated by the symbols *, +, A, B, C etc. against the card sequence numbers in Table A1. The - symbol indicates that the following card (in LOWTRAN 2) has been removed.

Table A1. Listing of Fortran Code LOWTRAN 3

```
      PROGRAM LOWTRAN(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      COMMON Z(34),P(7,34),T(7,34),FH(10,34),WH(7,34),M,NL,RE,DH,CO,PI
      DIMENSION WO(7,34),HZ1(34),HZ2(9),AHAZE(34),AHZ2(20)
      DIMENSION TP(67),FW(67),FO(67),HZ(2),TX(10),VH(10),W(10),E(10)
      DIMENSION C1(2589), C2(1575), C3(540), C4(133), C5(15), C8(102)
      DIMENSION VX(45),C7(45),C7A(45)
      F(A)=EXP(18.9766-14.9595*A-2.43882*A*A)*A
      DATA HZ(1)/5H23 KM/,HZ(2)/5H 5 KM/
C***********************************************************************
C     PROGRAM LOWTRAN3 CALCULATES THE TRANSMITTANCE OF THE ATMOSPHERE
C     FROM 350 CM-1 TO 40000 CM-1 (0.25 TO 28.57 MICRONS) AT 20 CM-1
C     SPECTRAL RESOLUTION ON A LINEAR WAVENUMBER SCALE.
C     REFRACTION AND EARTH CURVATURE EFFECTS ARE INCLUDED.    ATMOSPHERE
C     IS LAYERED IN ONE KM. INTERVALS BETWEEN 0 AND 25 KM., 5 KM. INTER-
C     VALS TO 50 KM., A TWENTY KM. INTERVAL TO 70 KM., AND A THIRTY KM.
C     INTERVAL TO 100 KM.
C***********************************************************************
C     PROGRAM ACTIVATED BY SUBMISSION OF FOUR CARD SEQUENCE AS FOLLOWS
C
C   CARD 1 MODEL,IHAZE,ITYPE,LEN,JP,IM,M1,M2,M3,ML,RO  FORMAT(10I3,F10.3)
C   CARD 2 H1,H2,ANGLE,RANGE,BETA,VIS                  FORMAT(7F10.3)
C   CARD 3 V1, V2, DV                                  FORMAT(7F10.3)
C   CARD 4 IXY                                         FORMAT(I3)
C
C     MODEL=1,2,3,4,5 OR 6 SELECTS ONE OF THE FOLLOWING MODEL ATMOSPHERE
C     TROPICAL,MIDLATITUDE SUMMER,MIDLATITUDE WINTER,SUBARCTIC SUMMER,
C     SUBARCTIC WINTER,OR THE 1962 U.S.  STANDARD RESPECTIVELY
C     MODEL=0 FOR HORIZ. PATH WHEN METEOROL. DATA USED(INSTEAD OF CARD 2
C     READ H1,P(MB),T(DEG C),DEW PT.TEMP(DEG C),%REL HUMIDITY,H2O DENSITY
C     (GM.M-3),O3 DENSITY(GM.M-3), VIS(KM),RANGE(KM) WITH FORMAT 429.
C     MODEL=7 WHEN NEW MODEL ATMOSPHERE(E.G. RADIOSONDE DATA) USED.
C     DATA CARDS ARE READ IN BETWEEN CARDS 1 AND 2, AND SHOULD CONTAIN(
C     ALTITUDE(KM.),PRESSURE,TEMP,DEW PT.TEMP,REL. HUMIDITY,H2O DENSITY,
C     O3 DENSITY,AEROSOL NO. DENSITY(CM-3) ACCORDING TO FORMAT 429.
C     NOTE THAT EITHER DEW PT. TEMP.OR REL. HUMIDITY CAN BE USED.
C
C     M1,M2,M3, ARE USED TO CHANGE TEMP,H2O, AND O3 ALTITUDE PROFILES.
C
C     IF IHAZE=0 NO AEROSOL SCATTERING IS COMPUTED
C     IHAZE =1 IF AEROSOL ATTENUATION REQUIRED (THIS IS USED IN
C     CONJUNCTION WITH VISUAL RANGE(SEE CARD 2))
C     IHAZE = 1 OR 2 ALSO GIVE AEROSOL ATTENUATION FOR 23KM AND 5KM VIS.
C     HAZE MODELS RESPECTIVELY IF VIS =0 ON CARD 2
C
C     ITYPE=1,2  OR 3 INDICATES THE TYPE OF ATMOSPHERIC PATH
C     ITYPE=3,VERTICAL OR SLANT PATH TO SPACE
C     ITYPE=2,VERTICAL OR SLANT PATH BETWEEN TWO ALTITUDES
C     ITYPE=1, CORRESPONDS TO A HORIZONTAL (CONSTANT PRESSURE) PATH
C
C     H1=OBSERVER ALTITUDE (KM)
C     H2=SOURCE  ALTITUDE (KM)
C     ANGLE= ZENITH ANGLE AT H1 (DEGREES)
C     RANGE=PATH LENGTH (KM)
C     BETA=EARTH CENTRE ANGLE
C     VIS = VISUAL RANGE AT SEA LEVEL (KM)
C     (IF ITYPE=1 READ H1 AND RANGE:IF ITYPE=3 READ H1 AND ANGLE.
C     IF ITYPE=2 READ H1 AND TWO OTHER PARAMETERS E.G. H2 AND ANGLE)
C
C     V1=INITIAL FREQUENCY (WAVENUMBER CM-1 ) INTEGER VALUE
C     V2=FINAL FREQUENCY(WAVENUMBER CM-1 ) INTEGER VALUE
```

Table A1. Listing of Fortran Code LOWTRAN 3 (Cont)

```
C     DV= FREQUENCY INTERVALS AT WHICH TRANSMITTANCE IS PRINTED
C     NOTE: DV MUST BE A MULTIPLE OF 5 CM-1
C
C     IXY=0  TO END DATA ,=1 FOR NEW V1,V2,DV ONLY , =2 TO CONTINUE DATA
C     IXY=3 FOR NEW CARD 2 ONLY,=4 FOR NEW CARD 1 ONLY.
C*********************************************************************
      IXY=0
      READ (5,400) IATM,NL
      READ (5,401) (HZ1(I),I=1,NL)
      READ (5,401) (HZ2(I),I=1,5)
      DO 1 J=1,3
      K2=2*J
      K1=K2-1
      DO 1 I=1,NL
1     READ (5,402) Z(I),(P(K,I),T(K,I),WH(K,I),WO(K,I),K=K1,K2)
      READ (5,431) (VX(I),C7(I),C7A(I),I=1,44)
      READ (5,403) (TR(I),FH(I),FO(I),I=1,67)
      READ (5,404) (C1(I),I=1,2580)
      READ (5,404) (C2(I),I=1,1575)
      READ (5,404) (C3(I),I=1,540)
      READ (5,405) (C4(I),I=1,133)
      READ (5,404) (C5(I),I=1,15)
      READ (5,405) (C8(I),I=1,102)
      PI=2.0*ASIN(1.0)
      CA=PI/180.
      IP=0
2     CONTINUE
      RE=6371.23
      IFIND=0
C     JP NE 0  SUPRESS PRINT
      READ 400,MODEL,IHAZE,ITYPE,LEN,JP,IM,M1,M2,M3,ML,RO
      PRINT400,MODEL,IHAZE,ITYPE,LEN,JP,IM,M1,M2,M3,ML,RO
C     PRINT 424, MODEL,IHAZE,ITYPE,LEN
 200  M=MODEL
      IF (M.EQ.1) RE=6378.39
      IF (M.EQ.4) RE=6356.91
      IF (M.EQ.5) RE=6356.91
      IF(IXY.GT.3) GO TO 8
      IF(RO.NE.0.0) RE=RO
      IF(M.EQ.7.AND.IM.NE.0)GO TO 4
      IF (MODEL.EQ.0) GO TO 4
 300  READ 406, H1,H2,ANGLE,RANGE,BETA,VIS
      PRINT 425, H1,H2,ANGLE,RANGE,BETA,VIS
      X1=RE+H1
      IF (ITYPE.EQ.3) GO TO 560
      IF (ITYPE.EQ.1) GO TO 8
      X2=RE+H2
      IF (RANGE.EQ.0.) GO TO 5
      PRINT 428, H1,H2,ANGLE,RANGE,BETA,VIS
      IF (H2.EQ.0.AND.ANGLE.NE.0) GO TO 3
      ANGLE=ACOS(0.5*((H2-H1)*(1.+X2/X1)/RANGE-RANGE/X1))/CA
      GO TO 7
 3    X2=SQRT((X1/RANGE+RANGE/X1+2.0*COS(ANGLE*CA))*X1*RANGE)
      H2=X2-RE
      GO TO 7
 4    CONTINUE
      IF(ML.LE.0)ML=1
      DO 540 K=1,ML
      AHAZE(K)=0.0
      IF(M.EQ.0)READ 429,H1,P(7,1),TMP,DP,RH,WH(7,K),WO(7,K),VIS,RANGE
      IF(M.EQ.0)PRINT 430,H1,P(7,1),TMP,DP,RH,WH(7,K),WO(7,K),VIS,RANGE
```

```
      IF(M.GT.0)READ 429,Z(K),P(7,K),TMP,DP,RH,WH(7,K),WO(7,K),AHAZE(K)   A 103E
      J=IFIX(Z(K)+1.0E-6)+1.                                              A 103F
      IF(M.EQ.0)Z(K)=H1                                                   A 103G
      IF(Z(K).GE.25.0) J=(Z(K)-25.0)/5.0+26.                              A 103H
      IF(Z(K).GE.50.0) J=(Z(K)-50.0)/20.0+31.                             A 103I
      IF(Z(K).GE.70.0) J=(Z(K)-70.0)/30.0+32.                             A 103J
      IF(J.GT.33)J=33                                                     A 103K
      FAC=Z(K)-FLOAT(J-1)                                                 A 103L
      IF(J.LT.26) GO TO 500                                               A 103M
      FAC=(Z(K)-5.0*FLOAT(J-26)-25.)/5.                                   A 103N
      IF(J.GE.31) FAC=(Z(K)-50.0)/20.                                     A 103O
      IF(J.GE.32) FAC=(Z(K)-70.0)/30.                                     A 103P
      IF(FAC.GT.1.0) FAC=1.0                                              A 103Q
  500 L=J+1                                                               A 103R
      T(7,K)=TMP+273.15                                                   A 103S
      IF(M1.GT.0)T(7,K)=T(M1,J)*(T(M1,L)/T(M1,J))**FAC                    A 103T
      TT=273.15/T(7,K)                                                    A 103U
      IF(RH.LE.0.0) TT=273.15/(273.15+DP)                                 A 103V
      IF(WH(7,K).LE.0.0) WH(7,K)=F(TT)                                    A 103W
      IF(M2.GT.0)WH(7,K)=WH(M2,J)*(WH(M2,L)/WH(M2,J))**FAC                A 103X
      IF(RH.GT.0.0) WH(7,K)=0.01*RH*WH(7,K)                               A 103Y
      IF(M3.GT.0)WO(7,K)=WO(M3,J)*(WO(M3,L)/WO(M3,J))**FAC                A 103Z
      IF(Z(K).GE.5.0)GO TO 520                                            A 104A
      IF(AHAZE(K).EQ.0.0)AHZ2(K)=HZ2(J)*(HZ2(L)/HZ2(J))**FAC              A 104B
  520 IF(AHAZE(K).EQ.0.0)AHAZE(K)=HZ1(J)*(HZ1(L)/HZ1(J))**FAC             A 104C
      IF(MODEL.EQ.0)GO TO 8                                               A 104D
      IF(K.EQ.1)PRINT 441                                                 A 104E
      PRINT 429,Z(K),P(7,K),TMP,DP,RH,WH(7,K),WO(7,K),AHAZE(K)            A 104F
  540 CONTINUE                                                            A 104G
      IM=6                                                                A 104H
      NL=ML                                                               A 104I
      M1=0                                                                A 104J
      M2=0                                                                A 104K
      M3=0                                                                A 104L
C     NOTE THAT Z(I) MAY NOT CORRESPOND TO THE VALUES GIVEN FOR STANDARD  A 104M
C     MODEL ATMOSPHERES                                                   A 104N
      GO TO 300                                                           A 104O
  560 IF (RANGE.GT.0.0) GO TO 580                                         A 104P
      IF (H2.GT.0.0.AND.H2.LT.H1) IFIND=1                                 A 104Q
      GO TO 8                                                             A 104R
  580 ITYPE=2                                                             A 104S
      BETA=ACOS(0.5*(RANGE*RANGE/(X1*X2)-X2/X1-X1/X2))/CA                 A 104T
    5 IF (BETA.EQ.0.) GO TO 6                                             A 105
      IFIND=1                                                             A 106
      BET=CA*BETA                                                         A 107
      X2=RE+H2                                                            A 108
      ANGLE=ATAN(X2*SIN(BET)/(X2*COS(BET)-X1))/CA                         A 109
      RANGE=X2*SIN(BET)/SIN(ANGLE*CA)                                     A 110
      BET=BETA                                                            A 111
      GO TO 8                                                             A 112
    6 RANGE=(X2/X1)**2-(SIN(ANGLE*CA))**2                                 A 113
      IF (RANGE.GE.0.0) RANGE=X1*(SQRT(RANGE)-ABS(COS(ANGLE*CA)))         A 114
    7 IF (ANGLE.NE.0..OR.ANGLE.NE.180.) BET=ASIN(RANGE*SIN(ANGLE*CA)/X2)  A 115
      IF (ANGLE.LT.0.) ANGLE=ANGLE+PI                                     A 116
      IF (RANGE.LT.0.0) RANGE=-RANGE                                      A 117
      BET=BET/CA                                                          A 118
      PRINT 428, H1,H2,ANGLE,RANGE,BET,VIS                                A 119
    8 CONTINUE                                                            A 120A
      SUMA=0.                                                             A 120B
      IF(IXY.LE.2) READ 406,V1,V2,DV                                      A 121*
      IF(IXY.LE.2)PRINT 406,V1,V2,DV                                      A 122*
```

```
      IF (ITYPE.EQ.1) PRINT 407, H1,RANGE                              A 123
      IF (ITYPE.EQ.2) PRINT 408, H1,H2,ANGLE                           A 124
      IF (ITYPE.EQ.3) PRINT 409, H1,ANGLE                              A 125
      IF (MODEL.EQ.0) M=7                                              A 126A
      IF (M.EQ.7) PRINT 417, VIS                                       A 126B
      IF(VIS.LT.2.0.AND.VIS.GT.0.0) PRINT 442                          A 126C
      IF (M.EQ.1) PRINT 410, M                                         A 127
      IF (M.EQ.2) PRINT 411, M                                         A 128
      IF (M.EQ.3) PRINT 412, M                                         A 129
      IF (M.EQ.4) PRINT 413, M                                         A 130
      IF (M.EQ.5) PRINT 415, M                                         A 131
      IF (M.EQ.6) PRINT 414, M                                         A 132
      IF (IHAZE.EQ.0.) PRINT 426                                       A 133
      IF (M.NE.7.AND.IHAZE.GT.0) PRINT 416, IHAZE,HZ(IHAZE)            A 134*
      AVW=10000./V1                                                    A 135
      ALAM=10000./V2                                                   A 136
      PRINT 418, V1,V2,DV,ALAM,AVW                                     A 137
      AVW=0.5E-4*(V1+V2)                                               A 138
      AVW=AVW*AVW                                                      A 139
      CO=77.46+.459*AVW                                                A 140
      CN=43.487-0.3473*AVW                                             A 141
      IF (IFIND.EQ.1) GO TO 15                                         A 142
9     IF (IFIND.EQ.1) CALL ANGL (H1,H2,ANGLE,BETA,LEN,ML)              A 143*
      IFIND=0                                                          A 144
      IF (JP.EQ.0) PRINT 427                                           A 146*
      IF (ITYPE.EQ.1) GO TO 15                                         A 147
      DO 11 K=1,10                                                     A 148
      VH(K)=0.0                                                        A 149
11    CONTINUE                                                         A 150
      BETA=0.0                                                         A 151-
      SR=0.0                                                           A 153
      IP=0                                                             A 154-
C****  NOW DEFINE CONSTANT PRESSURE PATH QUANTITES  EH(1-8)            A 156
      Y=CA*ANGLE                                                       A 157
      SPHI=SIN(Y)                                                      A 158
      R1=(RE+H1)*SPHI                                                  A 159
      IF (H1.GT.Z(NL)) GO TO 13                                        A 160
      GO TO 15                                                         A 161
13    X=(RE+Z(NL))/(RE+H1)                                             A 162
      IF (SPHI.GT.X) GO TO 14                                          A 163
      H1=Z(NL)                                                         A 164
      J1=NL                                                            A 165
      SPHI=SPHI/X                                                      A 166
      ANGLE=180.0-ASIN(SPHI)/CA                                        A 167
      R1=(RE+H1)*SPHI                                                  A 168
      GO TO 15                                                         A 170
14    HMIN=R1-RE                                                       A 171
      PRINT 433, HMIN                                                  A 172
      GO TO 95                                                         A 173
15    DO 17 I=1,NL                                                     A 174
      PS=P(M,I)/1013.0                                                 A 175
      TS=273.15/T(M,I)                                                 A 176A
      IF(M1.GT.0.AND.M.LT.7)TS=273.15/T(M1,I)                          A 176B
      X=PS*TS                                                          A 177
      PT=PS*SQRT(TS)                                                   A 178
      D=0.1*WH(M,I)                                                    A 179
      IF(M2.GT.0.AND.M.LT.7) D=0.1*WH(M2,I)                            A 180*
      EH(1,I)=D*PT**0.9                                                A 181*
      EH(2,I)=X*PT**0.75                                               A 182*
      EH(4,I)=0.8*PT*X                                                 A 183
      PPW=4.56E-5*D*273.15/TS                                          A 184*
```

```
      EH(5,I)=(PPW+0.005*(PS-PPW))*D
      EH(6,I)=X
      HAZE=HZ1(I)
      IF(M.EQ.7) HAZE=AHAZE(I)
      IF(Z(I).GE.5.0) GO TO 150
      IF(IHAZE.EQ.2)HAZE=HZ2(I)
      IF(IHAZE.EQ.2.AND.M.EQ.7)HAZE=AHZ2(I)
      IF(VIS.LE.0.0) GO TO 150
      HAZE= 6.389*((HZ2(I)-HZ1(I))/VIS+HZ1(I)/5.0-HZ2(I)/23.0)
      IF (M.NE.7) GO TO 150
      HAZE=6.389*((AHZ2(I)-AHAZE(I))/VIS+AHAZE(I)/5.0-AHZ2(I)/23.0)
 150  IF(HAZE.LT.0.0) HAZE=0.0
      EH(7,I)=3.5336E-4*HAZE
      EH(8,I)=46.6667*WO(M,I)
      IF(M3.GT.0.AND.M.LT.7) EH(8,I)=46.667*WO(M3,I)
      EH(3,I)=EH(8,I)*PT**0.4
      EH(9,I)=1.0
      EH(10,I)=1.0E-6*(CO*X*1013.0/273.15-PPW*CW)
      IF (I.EQ.NL) GO TO 16
      IF (MODEL.EQ.0.AND.I.GE.1) GO TO 26
      T2=T(M,I+1)
      W2=WH(M,I+1)
      IF(M1.GT.0)T2=T(M1,I+1)
      IF(M2.GT.0)W2=WH(M2,I+1)
      PPW=4.56E-6*W2*T2
      EH(9,I)=0.5*(EH(10,I)+1.0E-6*(CO*P(M,I+1)/T2-PPW*CW))
 16   IF (I.EQ.NL) EH(9,I)=0.
      IF (H1.GE.Z(I)) J1=I
      IF (IFIND.EQ.0.OR.JP.EQ.0) PRINT 434, I,Z(I),(EH(K,I),K=1,10)
      EH(9,I)=EH(9,I)+1.0
 17   CONTINUE

      IP=1
      IK=0
      X1=H1
      CALL POINT (H1,YN,N,NP1,TX,IP)
      J1=N
      TX1=TX(9)
      DO 18 K=1,8
 18   E(K)=TX(K)
      IF (ITYPE.EQ.1) GO TO 26
      IF (ITYPE.EQ.3) H2=Z(NL)
      IF (ANGLE.GT.90.0) GO TO 28
 19   IF (ANGLE.GT.90.0.AND.NP1.GT.0) J1=J1+1
      J2=NL
      IF (ITYPE.EQ.3) GO TO 20
      CALL POINT (H2,YN,N,NP,TX,IP)
      J2=N
      IF (NP.GT.0) J2=J2-1
 20   DO 21 K=1,8
      EH(K,J1)=E(K)
      IF (ITYPE.EQ.3) GO TO 21
      EH(K,J2+1)=TX(K)
 21   CONTINUE
      IF (J1.EQ.J2) TX1=TX1+YN-EH(9,J1)
C****  NOW DEFINE VERTICAL PATH QUANTITIES VH(1-8)
      IF (JP.EQ.0) PRINT 420
      DO 25 I=J1,J2
      X1=Z(I)
      X2=Z(I+1)
      IF (I.EQ.J1) X1=H1
```

```
      IF (I.EQ.J2) X2=H2
      DZ=X2-X1
      IF (I.EQ.NL) DZ=Z(I)-Z(I-1)
      DS=DZ
C*****  UPWARD TRAJECTORY
      RX=(RE+X1)/(RE+X2)
      THETA=ASIN(SPHI)/CA
      PHI=ASIN(SPHI*RX)/CA
      BET=THETA-PHI
      SALP=RX*SPHI
      IF (SPHI.GT.1.E-10) DS=(RE+X2)*SIN(BET*CA)/SPHI
      BETA=BETA+BET
      PSI=BETA+PHI-ANGLE
      PHI=180.-PHI
      SR=SR+DS
      DO 24 K=1,8
      EV=DS*EH(K,I)
      IF (I.EQ.NL) GO TO 22
      IF (EH(K,I).EQ.0.0.OR.EH(K,I+1).EQ.0.0) GO TO 23
      IF (EH(K,I).EQ.EH(K,I+1)) GO TO 24
      EV=DS*(EH(K,I)-EH(K,I+1))/ALOG(EH(K,I)/EH(K,I+1))
      GO TO 24
22    IF (EH(K,I).EQ.0.0) GO TO 23
      IF (EH(K,I-1).EQ.0.0) GO TO 23
      IF (EH(K,I).EQ.EH(K,I-1)) GO TO 24
      EV=EV/ALOG(EH(K,I-1)/EH(K,I))
      GO TO 24
23    EV=0.
24    VH(K)=VH(K)+EV
      IF (JP.EQ.0) PRINT 435, I,X1,(VH(L),L=1,8),PSI,PHI,BETA,THETA,SR
      IF (I.GE.NL) GO TO 25
      IF (I+1.EQ.J2) EH(9,I+1)=YN
      IF (I.EQ.J1) EH(9,I)=TX1
      RN=EH(9,I+1)/EH(9,I)
      SPHI=SPHI*RX/RN
      IF (SALP.GE.RN) SPHI=SALP
25    CONTINUE
      GO TO 47
C**** HORIZONTAL PATH
26    DO 27 K=1,8
      W(K)=RANGE*EH(K,1)
      IF (MODEL.GT.0) W(K)=RANGE*TX(K)
27    CONTINUE
      GO TO 49
28    CONTINUE
C****   DOWNWARD TRAJECTORY
      K2=0
      IF (NP1.EQ.1) J1=J1-1
      J2=J1+1
      YN1=YN
      J=J1+1
      IF (H2.GT.Z(J1+1).OR.H1.EQ.H2) GO TO 30
      IF (NP1.EQ.1.AND.H2.GE.Z(J1+1)) GO TO 30
      CALL POINT (H2,YN,N,NP2,TX,IP)
      DO 29 K=1,8
29    W(K)=TX(K)
      TX2=TX(9)
      YN2=YN
      IF (H2.LT.H1) H=H2
      J2=N
      IF (J1.EQ.J2) TX2=TX1+YN2-EH(9,N)
```

```
      IF (H2.GT.H1) TX1=TX2
      IF (J1.EQ.J2.AND.H2.LT.H1) YN1=TX2
   30 A0=(RE+H1)*SPHI*YN1
      IF (H2.GE.H1) YN2=YN1
      DO 31 I=1,J1
      HMIN=A0/EH(9,I)-RE
      IF (I.EQ.J1) HMIN=A0/YN1-RE
      JMIN=I
      IF (HMIN.LE.Z(I+1)) GO TO 32
   31 CONTINUE
   32 X=HMIN
      IF (HMIN.LE.0) GO TO 34
      CALL POINT (X,YN,N,NP,TX,IP)
      JMIN=N
      TX3=TX(9)
      IF (J2.EQ.N.OR.J1.EQ.N) TX3=YN2+TX(9)-EH(9,N)
      IF (J1.EQ.N.AND.H2.GE.H1) GO TO 33
      HMIN=A0/TX3-RE
      IF (ABS(X-HMIN).GT.0.0001) GO TO 32
   33 IF (J1.EQ.N.AND.H2.GE.H1) YN1=TX3
      IF (J2.EQ.N.AND.J1.NE.J2) YN2=TX3
      IF (H2.GE.H1) TX2=TX3
      IF (H2.GE.H1) J2=N
      IF (H2.GE.H1.OR.H2.LT.HMIN) H=HMIN
      PRINT 436, HMIN
      IF (H2.LT.HMIN) PRINT 440, HMIN
      GO TO 35
   34 PRINT 436, HMIN
      IF (H2.LT.H1) GO TO 35
      IF (ITYPE.EQ.3.OR.H2.GE.H1) PRINT 437
      ITYPE=2
      TX2=EH(9,1)
      JMIN=0
      J2=1
      H2=0.0
      H=0.0
C****  NOW DEFINE VERTICAL PATH QUANTITIES VH(1-8)
   35 IF (JP.EQ.0) PRINT 420
      DO 40 I=1,NL
      J=J-1
      REF=EH(9,J)
      IF (I.EQ.1) REF=YN1
      IF (I.EQ.1.AND.K2.EQ.1) REF=YN2
      IF (J.EQ.J2.AND.K2.EQ.0) REF=TX2
      IF (I.NE.1) X1=Z(J+1)
      X2=Z(J)
      IF (J.EQ.J2.AND.K2.EQ.0) X2=H
      IF (J.EQ.JMIN.AND.K2.EQ.1) X2=HMIN
      HM=(RE+X1)*SPHI-RE
      IF (HM.GT.Z(J).AND.HM.GT.X2) X2=HM
      RX=(RE+X1)/(RE+X2)
      DS=X1-X2
      ALP=90.0
      THET=ASIN(SPHI)/CA
      SALP=RX*SPHI
      IF (ABS(X2-HM).GT.1.0E-5) ALP=ASIN(SALP)/CA
      BET=ALP-THET
      IF (SPHI.GT.1.0E-10) DS=(RE+X2)*SIN(BET*CA)/SPHI
      THETA=180.0-THET
      BETA=BETA+BET
      PSI=BETA-ALP-ANGLE+180.0
```

```
      SR=SR+DS
      DO 39 K=1,8
      AJ=EH(K,J)
      BJ=EH(K,J+1)
      IF (J.EQ.J1) BJ=E(K)
      IF (J.EQ.J2.AND.H2.LT.H1.AND.H2.GT.0.0) AJ=W(K)
      IF (J.EQ.JMIN.AND.H2.GE.H1) AJ=TX(K)
      IF (J.EQ.JMIN.AND.ABS(H2-HH).LT.1.0E-5) AJ=TX(K)
      IF (K2.EQ.0) GO TO 36
      IF (J.EQ.J2) BJ=W(K)
      IF (J.EQ.JMIN) AJ=TX(K)
36    IF (AJ.EQ.0.0.OR.BJ.EQ.0.0) GO TO 38
      IF (AJ.EQ.BJ) GO TO 37
      EV=DS*(AJ-BJ)/ALOG(AJ/BJ)
      GO TO 39
37    EV=DS*AJ
      GO TO 39
38    EV=0.0
39    VH(K)=VH(K)+EV
      IF (JP.EQ.0) PRINT 435, J,X1,(VH(L),L=1,8),PSI,ALP,BETA,THETA,SR
      IF (J.EQ.J2.AND.H2.GE.H1) GO TO 45
      IF (J.EQ.JMIN.AND.K2.EQ.1) GO TO 43
      IF (J.NE.1) RN=REF/EH(9,J-1)
      IF (J.EQ.J2+1) RN=REF/TX2
      IF (J.EQ.J2.AND.K2.EQ.0) RN=REF/YN2
      IF (J.EQ.(JMIN+1).AND.K2.EQ.1) RN=REF/TX3
      IF (SALP.GE.RN) RN=1.0
      SPHI=SALP*RN
      IF (J.EQ.J2.AND.K2.EQ.0) GO TO 41
40    CONTINUE
41    IF (HMIN.LE.0) GO TO 47
      IF (LEN.EQ.0) PRINT 438
      IF (LEN.EQ.0) GO TO 47
      IF (LEN.EQ.1) PRINT 439
      K2=1
      X1=X2
      IF (ABS(X1-HMIN).LE.0.001) GO TO 47
      H=HMIN
      J=J2+1
      IF (NP2.EQ.1) J=J-1
      B=BETA
      PH=180.0-ASIN(SPHI)/CA
      TS=SR
      PS=PSI
      DO 42 K=1,8
42    E(K)=VH(K)
      GO TO 35
43    BETA=2.*BETA-B
      PSI=2.*PSI-PS
      SR=2.*SR-TS
C      LONG PATH  TAKEN
      PHI=PH
      DO 44 K=1,8
44    VH(K)=2.*VH(K)-E(K)
      GO TO 47
45    DO 46 K=1,10
46    VH(K)=2.0*VH(K)
      BETA=2.0*BETA
      SR=2.0*SR
      IF (H2.EQ.H1) GO TO 47
      RN=TX1/YN1
```

Table A1. Listing of Fortran Code LOWTRAN 3 (Cont)

```
      SPHI=SIN(ANGLE*CA)
      IF (SPHI.LT.RN) SPHI=SPHI/RN
      GO TO 19
47    CONTINUE
      PRINT 406, HM
      DO 48 K=1,10
      W(K)=VH(K)
48    CONTINUE
49    WRITE (6,419)
      WRITE (6,421) (W(I),I=1,8)
      I=1
      L=1
      IV1=V1/5.0
      IV2=V2/5.+.99
      IV1=5*IV1
      IV2=5*IV2
      IF (IV1.LT.350) IV1=350
      IF (IV2.GT.50000) IV2=50000
      IF (DV.LT.5.) DV=5.
      IDV=DV
      IV=IV1-IDV
      ICOUNT=0
C****  BEGINING OF TRANSMITTANCE CALCULATIONS
50    IV=IV+IDV
      IF(JP.NE.0) GO TO 52
      IF (ICOUNT.EQ.0) GO TO 51
      IF (ICOUNT.EQ.50) GO TO 51
      GO TO 52
51    ICOUNT=0
      PRINT 422
52    DO 53 K=1,10
      TX(K)=0.0
      IF (K.LT.4) TX(K)=1.0
53    CONTINUE
      ICOUNT=ICOUNT+1
      SUM=0.0
      V=IV
      I=(IV-350)/5+1
      IF (IV.LT.1400) GO TO 61
      IF (IV.LT.2740) GO TO 68
C*********   MOLECULAR SCATTERING
      C6=9.807E-20*(V**4.0117)
      TX(6)=C6*W(6)
      SUM=SUM+TX(6)
      IF (IV.LT.9200) GO TO 72
      IF (IV.LT.13000) GO TO 69
C*********   UV OZONE
      IF (IV.LE.23400) GO TO 54
      IF (IV.GE.27500) GO TO 55
      GO TO 87
54    XX=200.0
      XI=(V-13000.0)/XX+1.0
      L1=1
      L2=53
      GO TO 56
55    XX=500.0
      XI=(V-27500.0)/XX+57.0
      L1=57
      L2=102
56    DO 57 N=L1,L2
      XD=XI-FLOAT(N)
```

Table A1. Listing of Fortran Code LOWTRAN 3 (Cont)

```
      IF (XD) 59,58,57
57    CONTINUE
58    TX(8)=W(8)*C8(N)
      GO TO 60
59    TX(8)=C8(N)+XD*(C8(N)-C8(N-1))
      TX(8)=W(8)*TX(8)
60    SUM=SUM+TX(8)
      IF(IV.GT.14500)GO TO 97
      GO TO 69
C********    WATER VAPOUR CONTINUUM
61    IF (IV.LE.670) GO TO 72
      IF (IV.LT.700) GO TO 66
      XI=(V-700.)/50.+1.
      DO 63 NH=1,15
      XH=XI-FLOAT(NH)
      IF (XH) 65,64,63
63    CONTINUE
64    TX(5)=C5(NH)
      GO TO 67
65    TX(5)=C5(NH)+XH*(C5(NH)-C5(NH-1))
      GO TO 67
66    TX(5)=(V-670.)*0.09
67    TX(5)=W(5)*TX(5)
      SUM=SUM+TX(5)
      GO TO 72
C********    NITROGEN CONTINUUM
68    IF (IV.LT.2080) GO TO 72
      K4=I-346
      TX(4)=C4(K4)*W(4)
      SUM=SUM+TX(4)
      GO TO 72
C********  WATER VAPOUR
69    IF (IV.LT.12800.AND.IV.GE.9875) GO TO 70
      IF (IV.LE.14520.AND.IV.GE.13400) GO TO 71
      GO TO 76
70    I=I-135
      GO TO 72
71    I=I-255
72    K1=1
      IF (W(1).LT.1.0E-20) GO TO 76
      WS1=ALOG10(W(1))+C1(I)
      IF (WS1.LT.-2.3468) GO TO 76
      IF (WS1.GT.2.0) K1=40
      IF (WS1.GT.3.5682) GO TO 75
      DO 73 K=K1,67
      IF (WS1.LE.FW(K)) GO TO 74
73    CONTINUE
74    TX(1)=TR(K)+(TR(K-1)-TR(K))*(FW(K)-WS1)/(FW(K)-FW(K-1))
      GO TO 76
75    TX(1)=0.0
76    CONTINUE
C********    UNIFORMLY MIXED GASES
      IF (IV.LT.8060.AND.IV.GE.500) GO TO 77
      IF (IV.LT.13130.AND.IV.GT.12970) GO TO 78
      GO TO 83
77    J=I-30
      GO TO 79
78    J=(IV-12950)/5+1516
79    IF(W(2).LT.1.0E-20) GO TO 83
      K1=1
      WS2=ALOG10(W(2))+C2(J)
```

```
      IF (WS2.LT.-2.3468) GO TO 83
      IF (WS2.GT.3.5682) GO TO 82
      IF (WS2.GT.2.8) K1=48
      DO 80 K=K1,67
      IF (WS2.LE.FW(K)) GO TO 81
80    CONTINUE
81    TX(2)=TR(K)+(TR(K-1)-TR(K))*(FW(K)-WS2)/(FW(K)-FW(K-1))
      GO TO 83
82    TX(2)=0.0
83    CONTINUE
C*********  OZONE
      IF (IV.LT.575.OR.IV.GT.3270) GO TO 87
      L=I-45
      K1=1
      IF (W(3).LT.1.0E-20) GO TO 87
      WS3=ALOG10(W(3))+C3(L)
      IF (WS3.LT.-1.6778) GO TO 87
      IF (WS3.GT.3.3345) GO TO 86
      IF (WS3.GT.1.5) K1=36
      DO 84 K=K1,67
      IF (WS3.LE.FO(K)) GO TO 85
84    CONTINUE
85    TX(3)=TR(K)-(TR(K)-TR(K-1))*(FO(K)-WS3)/(FO(K)-FO(K-1))
      GO TO 87
86    TX(3)=0.0
87    CONTINUE
C*********   AEROSOL EXTINCTION
      ALAM=1.0E+4/V
      XX=0.0
      YY=0.0
      IF (IHAZE.EQ.0.) GO TO 90
      DO 88 N=1,44
      XD=ALAM-VX(N)
      IF(XD)89,88,88
88    CONTINUE
89    XX=(C7(N)-C7(N-1))*XD/(VX(N)-VX(N-1))+C7(N)
      YY=(C7A(N)-C7A(N-1))*XD/(VX(N)-VX(N-1))+C7A(N)
90    TX(10)=YY*W(7)
      TX(7)=XX*W(7)
      SUM=SUM+TX(7)
      TX(9)=SUM
      DO 94 K=4,10
      IF (TX(K).EQ.0.0) GO TO 92
      IF (TX(K).LE.0.1) GO TO 91
      IF (TX(K).GT.20.) GO TO 93
      TX(K)=EXP(-TX(K))
      GO TO 94
91    TX(K)=1.0-TX(K)+0.5*TX(K)*TX(K)
      GO TO 94
92    TX(K)=1.0
      GO TO 94
93    TX(K)=0.
94    CONTINUE
      TX(10)=1.0-TX(10)
      TX(9)=TX(1)*TX(2)*TX(3)*TX(9)
      IF (IV.GE.13000) TX(3)=TX(8)
      IF(JP.EQ.1)TX(9)=TX(7)
      AB=1.-TX(9)
      IF(IV.EQ.IV1.OR.IV.EQ.IV2) AB=0.5*AB
      SUMA=SUMA+AB*DV
      IF(JP.EQ.0) WRITE(6,423) IV,ALAM,TX(9),(TX(K),K=1,7),TX(10),SUMA
```

Table A1. Listing of Fortran Code LOWTRAN 3 (Cont)

```
      IF (IV.GE.IV2) GO TO 95                                           A 588
      GO TO 50                                                          A 589
   95 READ 400, IXY                                                     A 590
      AB=1.-SUMA/V2-V1                                                  A 591A
      PRINT 424, IV1,IV2,SUMA,AB                                        A 591B
      PRINT 400,IXY                                                     A 591C
      IF(IXY.EQ.0) GO TO 190                                            A 591D
      GO TO (96,2,97,98,100),IXY                                        A 591E
   96 READ 406, V1,V2,DV                                                A 592
      AVW=10000./V1                                                     A 593
      ALAM=10000./V2                                                    A 594
      PRINT 418, V1,V2,DV,ALAM,AVW                                      A 595
      SUMA=0.0                                                          A 596*
      GO TO 49                                                          A 597
   97 IF(MODEL.EQ.0) GO TO 200                                          A 598A
      GO TO 300                                                         A 598B
   98 READ 400,MODEL,IHAZE,ITYPE,LEN,JP,IM,M1,M2,M3,ML,RO               A 598C
      PRINT 400,MODEL,IHAZE,ITYPE,LEN,JP,IM,M1,M2,M3,ML,RO              A 598D
      GO TO 200                                                         A 598E
  100 STOP                                                              A 599*
  400 FORMAT(10I3,F10.3)                                                A 600*
  401 FORMAT (8E10.3)                                                   A 601
  402 FORMAT (F6.1,2(E10.3,F6.1,2E10.1))                                A 602
  403 FORMAT (4(F6.3,2F7.4))                                            A 603
  404 FORMAT (15F5.2)                                                   A 604
  405 FORMAT (8E9.2)                                                    A 605
  406 FORMAT (7F10.3)                                                   A 606
  407 FORMAT (//10X,28H HORIZONTAL PATH, ALTITUDE =,F7.3,11H KM,RANGE =, A 607
     1F7.3,3H KM)                                                       A 608
  408 FORMAT (//10X,50H SLANT PATH BETWEEN ALTITUDES H1 AND H2 WHERE H1 A 609
     1=,F7.3,8H KM H2 =,F7.3,18H KM,ZENITH ANGLE =,F7.3,8H DEGREES)     A 610
  409 FORMAT (//10X,39H SLANT PATH TO SPACE FROM ALTITUDE H1 =,F7.3,19H A 611
     1KM, ZENITH ANGLE =,F7.3,8H DEGREES)                               A 612
  410 FORMAT (/20X,18H MODEL ATMOSPHERE ,I1,11H = TROPICAL)             A 613
  411 FORMAT (/20X,18H MODEL ATMOSPHERE ,I1,21H = MIDLATITUDE SUMMER)   A 614
  412 FORMAT (/20X,18H MODEL ATMOSPHERE ,I1,21H = MIDLATITUDE WINTER)   A 615
  413 FORMAT (/20X,18H MODEL ATMOSPHERE ,I1,21H = SUB-ARCTIC SUMMER )   A 616
  414 FORMAT (/20X,18H MODEL ATMOSPHERE ,I1,21H = 1962 US STANDARD  )   A 617
  415 FORMAT (/20X,18H MODEL ATMOSPHERE ,I1,21H = SUB-ARCTIC WINTER )   A 618
  416 FORMAT (/20X,18H        HAZE MODEL ,I1,3H = ,A5,13H VISUAL RANGE) A 619
  417 FORMAT (/25X*HAZE MODEL  =*,F5.1,* KM VISUAL RANGE AT SEA LEVEL*) A 620
  418 FORMAT (/10X,21H FREQUENCY RANGE V1= ,F7.1,13H CM-1 TO V2= ,F7.1,1 A 621
     14H CM-1 FOR DV =,F6.1,9H CM-1   (,F6.2,* - *,F5.2,* MICRONS )*)   A 622
  419 FORMAT (/10X,38H EQUILAVENT SEA LEVEL ABSORBER AMOUNTS//21X113HWAT A 623
     1ER VAPOUR      CO2 ETC.       OZONE     NITROGEN (CONT)  H2O (CONT) A 624
     2    MOL  SCAT      AEROSOL     OZONE(U-V)/24X,7HGM CM-2,10X,2HKM,1 A 625
     30X,6HATM CM,10X,2HKM,9X,7HGM CM-2,10X,2HKM,13X,2HKM,10X,6HATM CM) A 626
  420 FORMAT (1H1,///10X,*  VERTICAL PROFILES  *,64X,*PSI*,6X,*PHI*,6X,* A 627
     1BETA*,4X,*THETA    RANGE*)                                        A 628
  421 FORMAT (/10X,9H W(1-8)=8(F14.3)/)                                 A 629
  422 FORMAT (1H1,/10X,32H  FREQ WAVELENGTH  TOTAL      H2O,5X4HCO2+,5X,6 A 630*
     14HOZONE  N2 CONT  H2O CONT MOL SCAT  AEROSOL  AEROSOL   INTEGRATED A 631*
     2 /11X,16H CM-1  MICRONS,8(4X5HTRANS),4X,20H ABS     ABSORPTION )  A 632*
  423 FORMAT (10X,I6,10F9.4,F12.2)                                      A 633*
  424 FORMAT (* INTEGRATED ASOPPTION FROM*,I5,* TO*,I5,* CM-1 =*,F10.2, A 634A
     1*,AVERAGE TRANSMITTANCE =*,F6.4)                                  A 634B
  425 FORMAT (10X,7F10.3)                                               A 635
  426 FORMAT (/20X,*AEROSOL SCATTERING NOT COMPUTED,IHAZE=0*)           A 636
  427 FORMAT (1H1,///10X,20H HORIZONTAL PROFILES/)                      A 637
  428 FORMAT (10X,* H1=*,F7.3,*KM,H2=*,F7.3,*KM,ANGLE=*,F8.4,*GEOM. RANG A 638
     1E =*,F7.2,*KM,BETA=*,F8.5,*,VIS=*,F5.1)                           A 639
  429 FORMAT(3F10.3,2F5.1,2F10.3,2F10.3)                                A 640*
  430 FORMAT(10X,*INPUT METEOROLOGICAL DATA:*/10X,*Z=*,F7.2,* KM, P=*,F7 A 641*
```

```
     1.2,* MB,T=*,F5.1,* C, DEW PT.TEMP*,F5.1,* C, REL HUMIDITY=*,F5.1,  A 642*
     2* %, H2O DENSITY=*,1PE9.2,* GM M-3*/10X,* OZONE DENSITY=*,E9.2,* G A 643*
     3M-3, VISUAL RANGE=*,0PF6.1,* KM,RANGE=*,F10.3,* KM *  )            A 644*
431  FORMAT(4(F6.2,2F7.5))                                               A 645*
432  FORMAT (* STARTING PARAMETERS H1 AND ANGLE HAVE BEEN REDEFINED;H1=  A 646
     1 *,F10.3,*ANGLE =*,F10.6)                                          A 647
433  FORMAT (* TRAJECTORY MISSES EARTHS ATMOSPHERE. CLOSEST DISTANCE OF  A 648
     1 APPROACH IS*,F10.3,1X,/,1X,*END OF CALCULATION*)                  A 649
434  FORMAT (10X,I4,F6.1,11(F10.3))                                      A 650
435  FORMAT (I5,F7.1,8E10.3,4F9.4,F7.1)                                  A 651
436  FORMAT (* HMIN = *,F10.3)                                           A 652
437  FORMAT (* PATH INTERSECTS EARTH - PATH CHANGED TO TYPE 2 WITH H2 =  A 653
     1 0.0 KM*)                                                          A 654
438  FORMAT (* CHOICE OF TWO PATHS FOR THIS CASE -SHORTEST PATH TAKEN.   A 655
     1 FOR LONGER PATH SET LEN=1.*)                                      A 656
439  FORMAT (* CHOICE OF TWO PATHS FOR THIS CASE -LONGEST PATH TAKEN.    A 657
     1 FOR SHORT PATH SET LEN = 0 *)                                     A 658
440  FORMAT (* H2 HAS SET LESS THAN HMIN AND HAS BEEN RESET EQUAL TO     A 659
     1  HMIN I.E. H2 = *,F10.3)                                          A 660
441  FORMAT(*  MODEL ATMOSPHERE NO. 7*,/ 4X,*Z (KM)*,3X,*P (MB)*,4X,     A 661*
     1 *T (C) DEW PT %RH  H2O(GM.M-3) O3(GM.M-3) NO  DEN.*)              A 662*
442  FORMAT(*  FOG CONDITIONS MAY EXIST AT SEA LEVEL FOR THIS VISUAL RA  A 663*
     1NGE*,/,*  IF SO THEN ASSUME THE TRANSMITTANCE DUE TO FOG IS GIVEN  A 664*
     1BY THE TRANSMITTANCE AT 0.55 MICRONS*)                             A 665*
      END                                                                A 666*
```

```
      SUBROUTINE POINT (X,YN,N,NP,TX,IP)                                 B   1
      COMMON Z(34),P(7,34),T(7,34),EH(10,34),HH(7,34),M,NL,RE,DW,DO,PI   B   2*
      DIMENSION TX(10)                                                   B   3
C*********************************************************************  B   4
C     SUBROUTINE POINT COMPUTES THE MEAN REFRATIVE INDEX ABOVE AND BELOW B   5
C     A GIVEN ALTITUDE AND INTERPOLATES EXPONENTIALLY TO DETERMINE THE   B   6
C     EQUIVALENT ABSORBER AMOUNTS AT THAT ALTITUDE.                      B   7
C                                                                        B   8
C*********************************************************************  B   9
C                                                                        B  10
C      X IS THE HEIGHT IN QUESTION                                       B  11
C      TX(9) AND YN ARE THE MEAN REFRACTIVE INDICES ABOVE AND BELOW X    B  12
C      N IS THE LEVEL INTEGER CORRESPONDING TO X OR THE LEVEL BELOW X    B  13
C      NP =1 IF X COINCIDES WITH MODEL ATMOSPHERE LEVEL ,IF NOT NP = 0   B  14
C      TX(1-8) ARE ABSORBER  AMOUNTS PER KM AT HEIGHT X                  B  15
C*********************************************************************  B  16*
      N=NL                                                               B  17*
      NP=0                                                               B  18
      IF (X.LT.0.0) X=0.                                                 B  19A
      IF (X.GT.Z(NL)) GO TO 4                                            B  19B
      DO 1 I=1,NL                                                        B  20
      N=I                                                                B  21
      IF (X-Z(I)) 2,4,1                                                  B  22
1     CONTINUE                                                           B  23-
2     J2=N                                                               B  25
      N=N-1                                                              B  26
      FAC=(X-Z(N))/(Z(J2)-Z(N))                                          B  27
      PX1=P(M,N)*(P(M,J2)/P(M,N))**FAC                                   B  28
      TX1=T(M,N)*(T(M,J2)/T(M,N))**FAC                                   B  29
      WX1=WH(M,N)*(WH(M,J2)/WH(M,N))**FAC                                B  30
```

Table A1. Listing of Fortran Code LOWTRAN 3 (Cont)

```
      TX(3)=CO*PX1/TX1-4.56E-6*HX1*TX1*CW
      TX(2)=CO*P(M,J2)/T(M,J2)-4.56E-5*WH(M,J2)*T(M,J2)*CW
      TX(1)=CO*P(M,N)/T(M,N)-4.56E-6*WH(M,N)*T(M,N)*CW
      TX(9)=0.5E-6*(TX(2)+TX(3))
      YN=0.5E-6*(TX(1)+TX(3))
      IF (IT.EQ.0) GO TO 9
      DO 3 K=1,8
      TX(K)=0.0
      IF (EH(K,N).EQ.0.0) GO TO 3
      IF (EH(K,N).GT.1000.0) GO TO 3
      TX(K)=EH(K,N)*(EH(K,J2)/EH(K,N))**FAC
3     CONTINUE
      GO TO 9
4     NP=1
      IF (IP.EQ.0) GO TO 6
      DO 5 K=1,8
5     TX(K)=EH(K,N)
6     TX(9)=EH(9,N)-1.
      YN=0.0
C*****  CARDS B 24 AND 50 THROUGH 59 ARE NO LONGER REQUIRED
      IF (N.GT.1) YN=EH(9,N-1)-1.0
9     CONTINUE
      IF (IP.EQ.1) PRINT 400, X,N,NP,TX(9),YN,IP,(TX(K),K=1,8)
      TX(9)=TX(9)+1.
      YN=YN+1.
      RETURN
C
400   FORMAT (/,* FROM POINT* HEIGHT=*,F10.4,* KM,N=*,I3,*,NP=*,I2,*,REF
     1. INDEX ABOVE & BELOW X=*,2E11.4,*,IP=*,I3,/,12X,*EQUIV. ABSORBER
     2AMOUNTS PER KM AT X=*,8E10.3)
      END



      SUBROUTINE ANGL (H1,H2,ANGLE,B1,LEN,ML)
      COMMON Z(34),P(7,34),T(7,34),EH(10,34),WH(7,34),M,NL,RE,CW,CO,PI
      DIMENSION TX(10)
C**********************************************************************
C
C     THIS SUBROUTINE CALCULATES THE INITIAL ZENITH ANGLE (ANGLE)
C     TAKING INTO ACCOUNT REFRACTION EFFECTS GIVEN H1,H2, AND BETA
C     (WHERE BETA IS THE EARTH CENTRE ANGLE SUBTENDED BY H1 AND H2 ),
C     ASSUMING THE REFRACTIVE INDEX TO BE CONSTANT IN A GIVEN LAYER.
C     FOR GREATER ACCURACY INCREASE THE NUMBER OF LEVELS IN THE MODEL
C     ATMOSPHERE.
C
C     THIS SUBROUTINE CAN BE REMOVED FROM THE PROGRAM IF NOT REQUIRED.
C**********************************************************************
      IP=99
      CA=PI/180.
      X1=RE+H1
      X2=RE+H2
      LEN=0.
      IT=0
      B1=B1*CA
      IF(B1.EQ.0.0) B1=ACOS(X2/X1)
      TANG=X2*SIN(B1)/(X2*COS(B1)-X1)
      THET=ATAN(TANG)
      IF (THET.LT.0.0) THET=THET+PI
      SPHI=SIN(THET)
```

Table A1. Listing of Fortran Code LOWTRAN 3 (Cont)

```
      ANG=THET/CA
C     PRINT 404, B1,ANG,TANG
      TN=THET
      TM=TN-0.5*CA
1     ANGLE=THET
      FBT=0.
      BETA=0.
      BET1=0
      BET2=0
      FBT1=0
      FBT2=0
      FBT3=0.0
      IF(B1.LE.0.0) GO TO 2
C     PRINT 400, IT
      Y=2.*THET
      IF (Y-PI.GT.1.0E-8) GO TO 9
      IF (IP.EQ.100) GO TO 6
      XMIN=X2*COS(B1)-RE
      IF (XMIN-H1) 8,4,4
2     HMIN=H2
      H2=H1
      H1=MIN
3     ANGLE=0.5*PI
      THET=ANGLE
      SPHI=1.0
      ANG=ANGLE/CA
C     PRINT 404, B1,ANG,SPHI
4     IP=100
      CALL POINT (H1,YN,N,NP,TX,IP)
      J1=N
      TX1=TX(9)
5     CALL POINT (H2,YN,N,NP,TX,IP)
      IF (NP.EQ.1) N=N-1
      J2=N
      IF (J1.EQ.J2) TX1=TX1+YN-EH(9,J1)
6     DO 7 J=J1,J2
      X1=RE+Z(J)
      X2=RE+Z(J+1)
      IF (J.EQ.J1) X1=RE+H1
      IF (J.EQ.J2) X2=RE+H2
      SALP=X1*SPHI/X2
      ALP=ASIN(SALP)
      RN=EH(9,J+1)/EH(9,J)
      IF ((J+1).EQ.J2) RN=YN/EH(9,J)
      IF (J.EQ.J1) RN=EH(9,J+1)/TX1
      IF ((J+1).EQ.J2.AND.J.EQ.J1) RN=YN/TX1
      BET=THET-ALP
      FB=-TAN(ALP)
      IF (J.NE.J1) FB=FB+TAN(THET)
      FBT=FBT+FB
      BETA=BETA+BET
      TH1=THET/CA
      BE=BET/CA
      C=ALP/CA
C     PRINT 402, J,Z(J),THET,ALP,BET,BETA,FBT,FB,TH1,BE,C
      IF (X2.EQ.RE+H2) C=PI-ALP
      IF (SALP.GE.RN) RN=1.
      SPHI=SALP/RN
      THET=ASIN(SPHI)
```

Table A1. Listing of Fortran Code LOWTRAN 3 (Cont)

```
7       CONTINUE                                                        C  81
        IF(B1.LE.0.0) GO TO 29                                          C  81+
        GO TO 26                                                        C  82
8       CONTINUE                                                        C  83
        TANG=-TANG                                                      C  84
        ANGLE=PI-ANGLE                                                  C  85
        TN=ANGLE                                                        C  86
        ANG=ANGLE/CA                                                    C  87
C       PRINT 404, B1,ANG,TANG                                          C  88
        IF (H1.LE.0.0) GO TO 3                                          C  89
9       CONTINUE                                                        C  90
        IP=101                                                          C  91
        CALL POINT (H1,YN,N,NP1,TX,IP)                                  C  92
        TX1=TX(9)                                                       C  93
        YN1=YN                                                          C  94
        IF (NP1.EQ.1) N=N-1                                             C  95
        J2=NL                                                           C  96A
        IF (M.EQ.7) J2=ML                                               C  96B
        J1=N                                                            C  97
        J=J1+1                                                          C  98
        IF (H2.GE.H1) GO TO 13                                          C  99
        CALL POINT (H2,YN,N,NP,TX,IP)                                   C 100
        TX2=TX(9)                                                       C 101
        YN2=YN                                                          C 102
        J2=N                                                            C 103
        IF (J1.EQ.J2) TX2=YN1+TX(9)-EH(9,J1)                            C 104
10      J=J-1                                                           C 105
        X1=RE+Z(J+1)                                                    C 106
        X2=RE+Z(J)                                                      C 107
        IF (J.EQ.J1) X1=RE+H1                                           C 108
        IF (J.EQ.J2) X2=RE+H2                                           C 109
        SALP=X1*SPHI/X2                                                 C 110
        HMIN=X1*SPHI-RE                                                 C 111
C       PRINT 402, J,X1,Z(J),SPHI,SALP,HMIN,RE                          C 112
        IF (SALP.LE.1.0) GO TO 11                                       C 113
        SALP=SPHI                                                       C 114
        IF (HMIN.GT.H2) GO TO 18                                        C 115
11      ALP=ASIN(SALP)                                                  C 116
        THET=ASIN(SPHI)                                                 C 117
        BET=ALP-THET                                                    C 118
        BET1=BET1+BET                                                   C 119
        FB=TAN(ALP)                                                     C 120
        IF (J.NE.J1) FB=FB-TAN(THET)                                    C 121
        FBT1=FBT1+FB                                                    C 122
        TH1=THET/CA                                                     C 123
        BE=BET/CA                                                       C 124
        AL=ALP/CA                                                       C 125
C       PRINT 402, J,X2,THET,ALP,BET1,BET,BMIN,HMIN,FBT1,TH1,BE,AL      C 126
        IF (X2.EQ.RE+H2) C=PI-ALP                                       C 127
        REF=EH(9,J)                                                     C 128
        IF (J.EQ.J1) REF=YN1                                            C 129
        IF (J.EQ.J2) REF=TX2                                            C 130
        IF (J.EQ.1) GO TO 12                                            C 131
        RN=EH(9,J)/EH(9,J-1)                                            C 132
        IF (J.EQ.J1) RN=YN1/EH(9,J-1)                                   C 133A
        IF(J.EQ.J2+1) RN=REF/TX2                                        C 133B
        IF(J.EQ.J2) RN=REF/YN2                                          C 133C
        IF (SALP.GE.RN) RN=1.                                           C 134
        SPHI=SALP*RN                                                    C 135
        IF (Z(J).LE.H2) GO TO 12                                        C 136
```

```
      GO TO 10
12    X1=X2
      IF (ABS(Z(J)-H2).LT.1.0E-10.AND.J.NE.1) GO TO 13
      GO TO 14
13    J=J-1
      X1=RE+Z(J+1)
      IF (J.EQ.J1) X1=RE+H1
      IF (J.EQ.J2.AND.J.NE.J1) X1=RE+H2
14    X2=RE+Z(J)
      HMIN=X1*SPHI-RE
      IF (HMIN.LE.0.0) GO TO 25
      IF (Z(J).LT.HMIN) GO TO 18
      REF=EH(9,J)
      IF (J.EQ.J2) REF=YN
      SALP=X1*SPHI/X2
      ALP=ASIN(SALP)
      THET=ASIN(SPHI)
      BET=ALP-THET
      FB=TAN(ALP)-TAN(THET)
      FBT2=FBT2+FB
      BET2=BET2+BET
      BMIN=BET1+BET2
      AL=ALP/CA
      TH1=THET/CA
C     PRINT 402, J,X2,THET,ALP,BET2,BET,BMIN,HMIN,FBT2,TH1,BE,AL
      RN=REF/EH(9,J-1)
      IF (SALP.GE.RN) RN=1.0
      SPHI=SALP*RN
      GO TO 13
17    TX3=YN1+TX(9)-EH(9,J1)
      YN1=TX3
      IF (ABS(H2-Z(J+1)).LE.1.0E-5) YN1=TX(9)
      IF (ABS(H1-Z(J+1)).LE.1.0E-5) YN1=TX(9)
      RN=1.0
      GO TO 19
18    CALL POINT (HMIN,YN,N,NP,TX,IP)
      IP=102
      TX3=TX(9)
      IF (J.EQ.J1.AND.H2.GE.H1) GO TO 17
      IF (J.EQ.J1.OR.J.EQ.J2) TX3=YN2+TX(9)-EH(9,J)
      IF (HMIN.GT.H2) TX3=TX(9)
      IF (J.EQ.J1.AND.HMIN.GT.H2) GO TO 17
      RN=REF/TX3
      IF (SALP.GE.RN) RN=1.
      SPHI=SALP*RN
      X=X1*SPHI-RE
      DIF=ABS(HMIN-X)
      HMIN=X
      IF (DIF-1.0E-5) 19,19,18
19    X2=RE+HMIN
C     PRINT 403, HMIN,DIF,RN
      THET=ASIN(SPHI)
      IF(RN.EQ.1.0) FBT3=-TAN(THET)
      IF (RN.EQ.1) GO TO 20
      DNX=(TX3-1.0)*ALOG((TX3-1.0)/(REF-1.0))/(X2-X1)
      FBT3=-TAN(THET)*(1.0-1.0/(1.0+TX3/(X2*DNX)))
20    BET=0.5*PI-THET
      BET2=BET2+BET
      BMIN=BET1+BET2
      IF (H2.GE.H1) GO TO 23
      BET=BET1+2.*BET2
      DB1=B1-BET1
```

Table A1. Listing of Fortran Code LOWTRAN 3 (Cont)

```
      DB2=BET-B1
21    DB3=ABS(BMIN-B1)
      IF(DB3.GT.DB1.AND.DB2.GT.DB1) GO TO 25
      IF(DB2.GT.DB3) GO TO 22
      IF(DB2.GT.DB1)  GO TO 25
      BETA=BET
      FBT=FBT1+2.0*(FBT2+FBT3)
      LEN=1.
      GO TO 26
22    BETA=BET1+BET2
      FBT=FBT1+FBT2+FBT3
C     PRINT 401, J,BETA,FBT,FBT1,FBT2,FBT3,TX1,YN1
      GO TO 26
23    BETA=2.0*(BET1+BET2)
      LEN=1.
      FBT=2.0*(FBT1+FBT2+FBT3)
      PRINT 401, J,BETA,FBT,FBT1,FBT2,FBT3,TX1,YN1
      IF (H2.EQ.H1) GO TO 26
      IP=103
      IF (NP1.EQ.1) J1=J1+1
      SPHI=SIN(ANGLE)
      IF (Z(J1+1).LE.H2) GO TO 24
      RN=TX1/YN1
      IF (SPHI.GE.RN) RN=1.
      SPHI=SPHI/RN
      THET=ASIN(SPHI)
      GO TO 5
24    CALL POINT (H2,YN,N,NP,TX,IP)
      TX1=TX1+YN-EH(9,J1)
      RN=TX1/YN1
      J2=J1
      IF (SPHI.GE.RN) RN=1.
      SPHI=SPHI/RN
      THET=ASIN(SPHI)
      GO TO 5
25    BETA=BET1
      LEN=0.
      FBT=FBT1
26    THET=ANGLE+(B1-BETA)/(1.+FBT/TANG)
      DBETA=BETA/CA
      B=BET1/CA
      TH1=THET/CA
      PRINT 404, BETA,DBETA,FBT,TH1,TANG
      IF (THET.GT.TN.OR.THET.LT.TM) THET=(TN+TM)/2.
      TH1=THET/CA
      PRINT 404, BET1,B,FBT,TH1
      TN1=TN/CA
      TM1=TM/CA
      PRINT 405, TN,TM,TN1,TM1
      SPHI=SIN(THET)
      TANG=TAN(THET)
      IT=IT+1
      DBE=ABS(B1-BETA)
      DTH=ABS(ANGLE-THET)
      IF (IT.EQ.10)  THET=0.5*(ANGLE+THET)
      IF (IT.EQ.10) GO TO 28
      IF (DBE.GT.1.0E-7.AND.DTH.GT.1.0E-7) GO TO 1
28    ANGLE=THET/CA
      PRINT 406, ANGLE,IT
```

```
      RETURN
29    H1=H2
      ANGLE=C/CA
      PRINT 406, ANGLE,IT
      RETURN
C
400   FORMAT (//* ITTERATION NUMBER *,I3,//)
401   FORMAT (I6,E16.7,8F13.5)
402   FORMAT (I4,F10.4,6E13.4,4F10.4/)
403   FORMAT (*  HMIN=*,F14.6,*  DIF=*E14.6,*  PR=*,E16.8)
404   FORMAT (* TOTAL BETA = *,F14.6,F15.5,*,FBT = *,E14.6,* THET =*,F10
     1.6,*TANG=*,F10.6,*)
405   FORMAT (5F12.6)
406   FORMAT (8X,/1H*,*ZENITH ANGLE =*,F7.3,* DEGREES :  RECOMPUTED
     1 FROM SUBROUTINE ANGL (ITTERATION*,I3,*)*)
      END
```

The input data given in Table A2 can be summarized as follows:

(1) The first card gives the number of model atmospheres IATM to be read in and the number of levels NL.

(2) The next six cards contain the haze number densities (HAZE 1 and HAZE 2). Units: cm^{-3}.

(3) The next 102 cards contain the model atmosphere data for the six geographical models (with two models for each altitude on one card). Units: altitude (km), pressure (mb), temperature (°K), H_2O den ity (gm m^{-3}), O_3 density (gm m^{-3}).

(4) The next 11 cards contain the aerosol extinction (C7) and absorption (C7A) coefficients as a function of wavelength VX. The order and units are as follows: VX (μm), C7 (km^{-1}) and C7A (km^{-1}).

(5) The next 17 cards contain the transmittance scale (TR) and logarithmic scaling factors for water vapor and the uniformly mixed gases (FW), and for ozone (FO). Units: H_2O ($\log_{10}$ gm cm^{-2}), uniformly mixed gases ($\log_{10}$ km), O_3 ($\log_{10}$ atm cm) respectively.

(6) The next 344 cards contain the spectral data for the various molecules in the following order: C1 (H_2O), C2 (uniformly mixed gases), C3 (ozone), C4 (nitrogan continuum), C5 (H_2O continuum), C8 (UV and visible ozone). The parameters C1, C2 and C3 are in the form of logarithmic absorption coefficients, with units $\log_{10}$ ($gm^{-1}\,cm^2$), $\log_{10}$ (km^{-1}) and $\log_{10}$ ($atm^{-1}\,cm^{-1}$), respectively. The units of C4 to C8 are km^{-1}.

(7) The last four cards contain the operational instructions for executing the program and are discussed in detail in Section 5.

A wavenumber (cm^{-1}) identification is given in the last 5 columns of the spectral data cards described above. Labels identifying the various card groups are also given in Table A2.

Table A2. Listing of Data for LOWTRAN 3

HAZE MODELS

```
 6 34                                                                            *
2.830E+03 1.245E+03 5.374E+02 2.257E+02 1.193E+02 8.992E+01 6.341E+01 5.993E+01
6.073E+01 5.822E+01 5.679E+01 5.320E+01 5.589E+01 5.159E+01 5.052E+01 4.747E+01
4.514E+01 4.460E+01 4.317E+01 3.636E+01 2.663E+01 1.935E+01 1.456E+01 1.114E+01
8.831E+00 7.434E+00 2.239E+00 5.893E-01 1.551E-01 4.084E-02 1.078E-02 5.553E-05
1.970E-08-0.
1.379E+04 5.034E+03 1.845E+03 6.735E+02 2.454E+02
```

MODEL ATMOSPHERES 1 & 2

```
  0.0 1.013E+03 300.0    1.9E 01    5.5E-05 1.013E+03 294.0    1.4E 01    6.0E-05
  1.0 9.040E+02 294.0    1.3E+01    5.5E-05 9.020E+02 290.0    9.3E+00    6.0E-05
  2.0 8.050E+02 288.0    9.3E+00    5.4E-05 8.020E+02 285.0    5.9E+00    6.0E-05
  3.0 7.150E+02 284.0    4.7E+00    5.1E-05 7.100E+02 279.0    3.3E+00    6.2E-05
  4.0 6.330E+02 277.0    2.2E+00    4.7E-05 6.280E+02 273.0    1.9E+00    6.4E-05
  5.0 5.590E+02 270.0    1.5E+00    4.5E-05 5.540E+02 267.0    1.0E+00    6.5E-05
  6.0 4.920E+02 264.0    8.5E-01    4.3E-05 4.670E+02 261.0    6.1E-01    6.3E-05
  7.0 4.320E+02 257.0    4.7E-01    4.1E-05 4.260E+02 255.0    3.7E-01    7.5E-05
  8.0 3.780E+02 250.0    2.5E-01    3.9E-05 3.720E+02 248.0    2.1E-01    7.3E-05
  9.0 3.290E+02 244.0    1.2E-01    3.9E-05 3.240E+02 242.0    1.2E-01    8.5E-05
 10.0 2.860E+02 237.0    5.0E-02    3.9E-05 2.810E+02 235.0    6.4E-02    9.0E-05
 11.0 2.470E+02 230.0    1.7E-02    4.1E-05 2.430E+02 229.0    2.2E-02    1.1E-04
 12.0 2.130E+02 224.0    6.0E-03    4.3E-05 2.090E+02 222.0    6.0E-03    1.2E-04
 13.0 1.820E+02 217.0    1.9E-03    4.5E-05 1.790E+02 216.0    1.8E-03    1.5E-04
 14.0 1.560E+02 210.0    1.0E-03    4.5E-05 1.530E+02 216.0    1.0E-03    1.9E-04
 15.0 1.320E+02 204.0    7.6E-04    4.7E-05 1.300E+02 216.0    7.6E-04    1.3E-04
 16.0 1.110E+02 197.0    6.4E-04    4.7E-05 1.110E+02 216.0    6.4E-04    2.1E-04
 17.0 9.370E+01 195.0    5.6E-04    6.3E-05 9.500E+01 216.0    5.6E-04    2.4E-04
 18.0 7.890E+01 193.0    5.0E-04    9.0E-05 8.120E+01 216.0    5.0E-04    2.9E-04
 19.0 6.660E+01 203.0    4.9E-04    1.4E-04 6.950E+01 217.0    4.9E-04    3.2E-04
 20.0 5.650E+01 207.0    4.5E-04    1.9E-04 5.950E+01 218.0    4.5E-04    3.4E-04
 21.0 4.800E+01 211.0    5.1E-04    2.4E-04 5.100E+01 219.0    5.1E-04    3.5E-04
 22.0 4.090E+01 215.0    5.1E-04    2.8E-04 4.370E+01 220.0    5.1E-04    3.5E-04
 23.0 3.500E+01 217.0    5.4E-04    3.2E-04 3.760E+01 222.0    5.4E-04    3.4E-04
 24.0 3.000E+01 219.0    6.0E-04    3.4E-04 3.220E+01 223.0    6.0E-04    3.2E-04
 25.0 2.570E+01 221.0    6.7E-04    3.4E-04 2.770E+01 224.0    6.7E-04    2.0E-04
 30.0 1.220E+01 232.0    3.6E-04    2.4E-04 1.320E+01 234.0    3.6E-04    2.0E-04
 35.0 6.000E+00 243.0    1.1E-04    9.2E-05 6.520E+00 245.0    1.1E-04    9.2E-05
 40.0 3.050E+00 254.0    4.3E-05    4.1E-05 3.330E+00 258.0    4.3E-05    4.1E-05
 45.0 1.590E+00 265.0    1.9E-05    1.3E-05 1.760E+00 270.0    1.9E-05    1.3E-05
 50.0 8.540E-01 270.0    6.3E-06    4.3E-06 9.510E-01 276.0    6.3E-06    4.3E-06
 70.0 5.790E-02 219.0    1.4E-07    8.5E-08 6.710E-02 218.0    1.4E-07    8.5E-08
100.0 3.000E-04 210.0    1.0E-09    4.3E-11 3.000E-04 210.0    1.0E-09    4.3E-11
99999.          210.0                                 210.0                       *
```

MODEL ATMOSPHERES 3 & 4

```
  0.0 1.018E+03 272.2    3.5E+00    6.0E-05 1.010E+03 287.0    9.1E+00    4.9E-05
  1.0 8.973E+02 268.7    2.5E+00    5.4E-05 8.960E+02 282.0    6.0E+00    5.4E-05
  2.0 7.897E+02 265.2    1.8E+00    4.9E-05 7.929E+02 276.0    4.2E+00    5.5E-05
  3.0 6.938E+02 261.7    1.2E+00    4.9E-05 7.000E+02 271.0    2.7E+00    5.9E-05
  4.0 6.081E+02 255.7    6.6E-01    4.9E-05 6.160E+02 266.0    1.7E+00    6.0E-05
  5.0 5.313E+02 249.7    3.8E-01    5.9E-05 5.410E+02 260.0    1.0E+00    6.4E-05
  6.0 4.627E+02 243.7    2.1E-01    6.4E-05 4.730E+02 253.0    5.4E-01    7.1E-05
  7.0 4.016E+02 237.7    8.5E-02    7.7E-05 4.130E+02 246.0    2.9E-01    7.5E-05
  8.0 3.673E+02 231.7    3.5E-02    9.0E-05 3.590E+02 239.0    1.3E-01    7.9E-05
  9.0 2.992E+02 225.7    1.6E-02    [illegible] 3.107E+02 232.0    4.2E-02    1.1E-04
 10.0 2.568E+02 219.7    7.5E-03    1.5E-04 2.677E+02 225.0    1.5E-02    1.3E-04
 11.0 2.199E+02 219.2    6.9E-03    2.1E-04 2.300E+02 225.0    9.4E-03    1.8E-04
 12.0 1.882E+02 218.7    6.0E-03    2.6E-04 1.977E+02 225.0    6.0E-03    2.1E-04
 13.0 1.610E+02 218.2    1.8E-03    3.0E-04 1.700E+02 225.0    1.8E-03    2.5E-04
 14.0 1.378E+02 217.7    1.0E-03    3.2E-04 1.460E+02 225.0    1.0E-03    2.8E-04
 15.0 1.179E+02 217.2    7.6E-04    3.4E-04 1.250E+02 225.0    7.6E-04    3.2E-04
 16.0 1.007E+02 216.7    6.4E-04    3.5E-04 1.080E+02 225.0    6.4E-04    3.4E-04
 17.0 8.610E+01 216.2    5.6E-04    3.9E-04 9.280E+01 225.0    5.6E-04    [illegible]
 18.0 7.350E+01 215.7    5.0E-04    4.1E-04 7.980E+01 225.0    5.0E-04    4.1E-04
 19.0 6.280E+01 215.2    4.9E-04    4.3E-04 6.860E+01 225.0    4.9E-04    4.1E-04
```

Table A2. Listing of Data for LOWTRAN 3 (Cont)

MODEL ATMOSPHERES 3 & 4 continued

20.0	5.370E+01	215.2	4.5E-04	4.3E-04	5.890E+01	225.0	4.5E-04	3.9E-04
21.0	4.580E+01	215.2	5.1E-04	4.3E-04	5.070E+01	225.0	5.1E-04	3.5E-04
22.0	3.910E+01	215.2	5.1E-04	4.3E-04	4.360E+01	225.0	5.1E-04	3.2E-04
23.0	3.340E+01	215.2	5.4E-04	4.3E-04	3.750E+01	225.0	5.4E-04	3.0E-04
24.0	2.860E+01	215.2	6.0E-04	3.5E-04	3.227E+01	226.0	6.0E-04	2.9E-04
25.0	2.430E+01	215.2	6.7E-04	3.4E-04	2.780E+01	228.0	6.7E-04	2.5E-04
30.0	1.110E+01	217.4	3.6E-04	1.9E-04	1.360E+01	235.0	3.6E-04	1.4E-04
35.0	5.180E+00	227.8	1.1E-04	9.2E-05	6.610E+00	247.0	1.1E-04	9.2E-05
40.0	2.530E+00	243.2	4.3E-05	4.1E-05	3.400E+00	262.0	4.3E-05	4.1E-05
45.0	1.290E+00	258.5	1.9E-05	1.3E-05	1.810E+00	274.0	1.9E-05	1.3E-05
50.0	6.820E-01	265.7	6.3E-06	4.3E-06	9.870E-01	277.0	6.3E-06	4.3E-06
70.0	4.670E-02	230.7	1.4E-07	8.5E-08	7.070E-02	216.0	1.4E-07	8.5E-08
100.0	3.000E-04	210.2	1.0E-09	4.3E-11	3.000E-04	210.0	1.0E-09	4.3E-11
99999.		210.0				210.0		*
0.0	1.013E+03	257.1	1.2E+00	4.1E-05	1.013E+03	288.1	5.9E+00	5.4E-05
1.0	8.878E+02	259.1	1.2E+00	4.1E-05	8.986E+02	281.6	4.2E+00	5.4E-05
2.0	7.775E+02	255.9	9.4E-01	4.1E-05	7.950E+02	275.1	2.9E+00	5.4E-05
3.0	6.798E+02	252.7	6.8E-01	4.3E-05	7.012E+02	268.7	1.8E+00	5.0E-05
4.0	5.932E+02	247.7	4.1E-01	4.5E-05	6.166E+02	262.2	1.1E+00	4.6E-05
5.0	5.158E+02	240.9	2.0E-01	4.7E-05	5.405E+02	255.7	6.4E-01	4.5E-05
6.0	4.467E+02	234.1	9.8E-02	4.9E-05	4.722E+02	249.2	3.8E-01	4.5E-05
7.0	3.853E+02	227.3	5.4E-02	7.1E-05	4.111E+02	242.7	2.1E-01	4.9E-05
8.0	3.308E+02	220.6	1.1E-02	9.0E-05	3.565E+02	236.2	1.2E-01	5.2E-05
9.0	2.829E+02	217.2	8.4E-03	1.6E-04	3.080E+02	229.7	4.6E-02	7.1E-05

MODEL ATMOSPHERES 5 & 6

10.0	2.418E+02	217.2	5.5E-03	2.4E-04	2.650E+02	223.2	1.8E-02	9.0E-05
11.0	2.067E+02	217.2	3.8E-03	3.2E-04	2.270E+02	216.8	8.2E-03	1.3E-04
12.0	1.766E+02	217.2	2.6E-03	4.3E-04	1.940E+02	216.6	3.7E-03	1.6E-04
13.0	1.510E+02	217.2	1.8E-03	4.7E-04	1.658E+02	216.6	1.8E-03	1.7E-04
14.0	1.291E+02	217.2	1.0E-03	4.9E-04	1.417E+02	216.6	8.4E-04	1.9E-04
15.0	1.103E+02	217.2	7.6E-04	5.6E-04	1.211E+02	216.6	7.2E-04	2.1E-04
16.0	9.431E+01	216.6	6.4E-04	6.2E-04	1.035E+02	216.6	6.1E-04	2.4E-04
17.0	8.058E+01	216.0	5.6E-04	6.2E-04	8.850E+01	216.6	5.2E-04	2.8E-04
18.0	6.882E+01	215.4	5.0E-04	6.2E-04	7.565E+01	216.6	4.4E-04	3.2E-04
19.0	5.875E+01	214.8	4.9E-04	6.0E-04	6.467E+01	216.6	4.4E-04	3.5E-04
20.0	5.014E+01	214.1	4.5E-04	5.5E-04	5.529E+01	216.6	4.4E-04	3.8E-04
21.0	4.277E+01	213.6	5.1E-04	5.1E-04	4.729E+01	217.6	4.8E-04	3.9E-04
22.0	3.647E+01	213.0	5.1E-04	4.7E-04	4.047E+01	218.6	5.2E-04	3.9E-04
23.0	3.109E+01	212.5	5.4E-04	4.3E-04	3.457E+01	219.6	5.7E-04	3.8E-04
24.0	2.649E+01	211.8	6.0E-04	3.5E-04	2.972E+01	220.6	6.1E-04	3.5E-04
25.0	2.256E+01	211.2	6.7E-04	3.2E-04	2.549E+01	221.6	6.6E-04	3.4E-04
30.0	1.020E+01	216.0	3.6E-04	1.5E-04	1.197E+01	226.5	3.8E-04	2.0E-04
35.0	4.701E+00	222.2	1.1E-04	9.2E-05	5.746E+00	236.5	1.6E-04	1.1E-04
40.0	2.243E+00	234.7	4.3E-05	4.1E-05	2.871E+00	253.4	6.7E-05	4.3E-05
45.0	1.113E+00	247.0	1.9E-05	1.3E-05	1.491E+00	264.2	3.2E-05	1.7E-05
50.0	5.719E-01	259.3	6.3E-06	4.3E-06	7.978E-01	270.6	1.2E-05	4.0E-06
70.0	4.016E-02	245.7	1.4E-07	8.0E-08	5.520E-02	219.7	1.5E-07	8.5E-08
100.0	3.800E-04	210.0	1.0E-09	4.3E-11	3.008E-04	210.0	1.0E-09	4.3E-11
99999.		210.0				210.0		*

AEROSOL SPECTRAL DATA

.20	.28600	.09530	.25	.28000	.05660	.31	.26200	.02060	.34	.24500	.01450	*
.49	.18500	.01050	.51	.17600	.01000	.63	.14600	.00914	.69	.13400	.00914	*
.86	.10800	.01020	1.06	.08910	.01380	1.54	.05790	.00924	2.00	.03510	.00348	*
2.50	.02660	.00369	2.70	.02670	.00388	3.00	.02240	.00487	3.20	.02150	.00232	*
3.39	.02990	.00222	3.50	.02100	.00171	3.75	.01950	.00143	4.00	.01820	.00154	*
4.50	.01670	.00249	5.50	.01360	.00295	6.00	.01190	.00360	6.50	.01210	.00423	*
7.20	.01330	.00629	7.90	.00784	.00504	8.20	.00809	.00702	8.50	.01530	.01160	*
8.70	.02190	.01180	9.00	.02380	.01310	9.20	.02350	.01430	9.50	.01850	.00937	*
10.00	.01570	.00698	10.59	.01350	.00549	11.00	.01220	.00439	13.00	.00938	.00386	*
14.80	.00827	.00464	15.00	.01010	.00691	17.20	.01100	.00607	18.50	.00923	.00506	*
20.00	.01010	.00567	25.00	.00878	.00565	27.90	.00821	.00562	30.00	.00838	.00501	*
0.999	-2.3468	-1.6778	0.998	-2.0362	-1.3980	0.996	-1.6930	-1.1192	0.994	-1.4815	-0.9566	
0.992	-1.3279	-0.8239	0.990	-1.2007	-0.7250	0.980	-0.7825	-0.4318	0.970	-0.5229	-0.2366	

Table A2. Listing of Data for LOWTRAN 3 (Cont)

TRANSMITTANCE FUNCTIONS

```
0.960-0.3468-0.1074 0.950-0.1938-0.        0.940-0.0655 0.0969 0.930 0.0414 0.1761
0.920 0.1553 0.2304 0.910 0.2430 0.3310 0.900 0.3324 0.3522 0.880 0.4342 0.4624
0.860 0.6128 0.5563 0.840 0.7243 0.6435 0.820 0.8261 0.7243 0.800 0.9191 0.7724
0.780 1.0090 0.8573 0.760 1.0757 0.9191 0.740 1.1461 0.9731 0.720 1.2122 1.0253
0.700 1.2672 1.0719 0.680 1.3264 1.1173 0.660 1.3892 1.1614 0.640 1.4403 1.2095
0.620 1.4955 1.2480 0.600 1.5441 1.2900 0.580 1.5966 1.3263 0.560 1.6435 1.3617
0.540 1.6857 1.3979 0.520 1.7340 1.4393 0.500 1.7792 1.4698 0.480 1.8261 1.4983
0.460 1.8692 1.5314 0.440 1.9191 1.5682 0.420 1.9638 1.6021 0.400 2.0086 1.6335
0.380 2.0607 1.6721 0.360 2.1038 1.7376 0.340 2.1461 1.7482 0.320 2.1875 1.7924
0.300 2.2304 1.8325 0.280 2.2788 1.8865 0.260 2.3263 1.9395 0.240 2.3717 2.0000
0.220 2.4183 2.0107 0.200 2.4698 2.1206 0.180 2.5159 2.1903 0.160 2.5740 2.2552
0.140 2.6284 2.3385 0.120 2.6922 2.4313 0.100 2.7559 2.5105 0.080 2.8261 2.6435
0.060 2.9031 2.7853 0.040 3.0000 2.9777 0.030 3.0607 3.1072 0.020 3.1461 3.2553
0.015 3.2041 3.3617 0.010 3.2718 3.4771 0.008 3.3054 3.5563 0.006 3.3644 3.6233
0.004 3.3979 3.7076 0.002 3.4916 3.8325 0.001 3.5682 3.9345
```

SPECTRAL DATA: H_2O

```
3.93 3.72 3.54 3.42 3.37 3.37 3.36 3.33 3.25 3.13 3.02 2.96 2.97 3.08 3.18  350
3.12 3.08 3.03 3.00 3.01 3.03 3.07 3.05 3.01 2.94 2.83 2.71 2.62 2.58 2.57  425
2.62 2.67 2.72 2.71 2.60 2.46 2.35 2.26 2.22 2.23 2.19 2.17 2.17 2.20 2.26  500
2.34 2.42 2.39 2.20 2.01 1.92 1.83 1.78 1.79 1.81 1.84 1.83 1.80 1.71 1.51  575
1.39 1.30 1.25 1.18 1.19 1.18 1.21 1.33 1.47 1.53 1.54 1.36 1.12 0.89 0.59  650
0.49 0.60 0.71 0.79 0.99 0.86 0.73 0.53 0.43 0.51 0.52 0.67 0.73 0.80 0.33  725
0.80 0.63 0.47 0.32-0.08-0.21-0.29-0.21-0.01 0.08 0.16 0.09-0.03-0.21-0.37  800
-0.35-0.30-0.31-0.37-0.42-0.48-0.42-0.40-0.39-0.43-0.77-0.83-0.88-0.79-0.60  875
-0.50-0.42-0.39-0.38-0.37-0.40-0.51-0.67-0.62-0.56-0.40-0.32-0.21-0.09-0.16  950
-0.16-0.19-0.28-0.33-0.35-0.28-0.22-0.10-0.05-0.11-0.13-0.27-0.27-0.19-0.06 1025
0.11 0.23 0.26 0.19 0.11-0.00-0.09 0.02 0.08 0.12 0.22 0.28 0.39 0.54 0.58 1100
0.75 0.79 0.79 0.71 0.69 0.76 0.80 1.01 1.16 1.10 1.14 1.05 1.02 1.11 1.23 1175
1.41 1.75 1.83 1.99 2.05 2.03 2.00 1.96 1.90 1.86 1.91 2.08 2.24 2.41 2.53 1250
2.68 2.67 2.73 2.79 2.81 2.91 2.93 3.02 3.16 3.23 3.30 3.34 3.43 3.57 3.59 1325
3.59 3.58 3.57 3.61 3.71 3.71 3.69 3.64 3.60 3.58 3.80 3.95 4.05 4.05 4.12 1400
3.99 3.96 4.01 4.13 4.22 4.35 4.49 4.58 4.62 4.63 4.61 4.57 4.56 4.56 4.53 1475
4.49 4.46 4.40 4.28 4.16 3.92 3.63 3.35 3.16 3.10 3.24 3.47 3.66 3.86 3.93 1550
4.00 4.04 4.15 4.23 4.31 4.35 4.31 4.23 4.20 4.24 4.28 4.35 4.42 4.42 4.44 1625
4.46 4.40 4.30 4.22 4.13 4.07 4.12 4.19 4.22 4.23 4.16 4.04 3.99 3.94 3.93 1700
3.91 3.86 3.83 3.90 3.78 3.70 3.54 3.40 3.30 3.31 3.42 3.52 3.52 3.49 3.41 1775
3.21 3.14 3.10 3.08 3.11 2.98 2.88 2.78 2.74 2.76 2.72 2.76 2.82 2.85 2.86 1850
2.75 2.64 2.60 2.61 2.66 2.56 2.49 2.37 2.25 2.14 2.08 2.11 2.20 2.31 2.28 1925
2.15 2.06 1.99 2.03 2.05 1.96 1.84 1.72 1.64 1.59 1.57 1.57 1.60 1.63 1.51 2000
1.38 1.07 0.91 0.87 0.92 1.04 1.01 0.92 0.84 0.92 0.97 1.01 1.06 1.10 1.36 2075
1.01 0.91 0.73 0.55 0.47 0.41 0.39 0.38 0.34 0.33 0.36 0.43 0.48 0.45 0.38 2150
0.27 0.21 0.22 0.29 0.37 0.38 0.37 0.29 0.19 0.13 0.11 0.03-0.05-0.12-0.24 2225
-0.31-0.39-0.43-0.50-0.59-0.68-0.73-0.80-0.92-1.06-1.14-1.22-1.27-1.28-1.33 2300
-1.32-1.43-1.51-1.63-1.74-1.82-1.98-2.09-2.21-2.21-2.24-2.27-2.36-2.51-2.55 2375
-2.70-2.63-2.57-2.56-2.59-2.67-2.69-2.67-2.68-2.62-2.52-2.42-2.29-2.14-2.00 2450
-1.87-1.71-1.51-1.39-1.27-1.12-1.01-0.89-0.75-0.66-0.57-0.47-0.42-0.32-0.27 2525
-0.26-0.19-0.13-0.11-0.01 0.05 0.08 0.17 0.25 0.31 0.41 0.43 0.44 0.43 0.36 2600
0.35 0.31 0.25 0.25 0.22 0.21 0.33 0.49 0.65 0.76 0.71 0.51 0.30 0.13 0.10 2675
0.17 0.24 0.31 0.39 0.45 0.51 0.56 0.60 0.63 0.62 0.63 0.64 0.66 0.69 0.76 2750
0.75 0.74 0.70 0.62 0.53 0.46 0.39 0.36 0.37 0.36 0.42 0.47 0.50 0.56 0.59 2825
0.67 0.62 0.64 0.68 0.76 0.90 1.11 1.13 1.10 0.97 0.98 1.17 1.30 1.52 1.70 2900*
1.76 1.86 1.92 1.90 1.87 1.91 2.02 2.13 2.10 2.18 2.22 2.25 2.03 2.01 1.77 2975*
1.93 2.19 2.28 2.14 2.15 2.22 2.01 2.14 2.26 2.36 2.51 2.66 2.73 2.68 2.59 3050*
2.64 2.22 1.95 1.61 1.11 0.88 0.83 0.89 1.20 1.62 1.62 1.99 2.01 2.14 2.16 3125*
2.21 2.30 2.33 2.42 2.50 2.51 2.49 2.46 2.42 2.37 2.37 2.33 2.31 2.43 2.56 3200*
2.61 2.63 2.60 2.50 2.38 2.41 2.34 2.31 2.32 2.40 2.27 2.32 2.22 2.09 2.60 3275*
2.17 2.51 2.77 2.68 2.49 2.29 2.23 2.42 2.61 2.58 2.49 2.40 2.39 2.51 2.50 3350*
2.68 2.68 2.70 2.82 2.83 2.82 2.81 2.84 2.86 2.91 2.96 3.03 3.08 3.21 3.30 3425*
3.40 3.52 3.49 3.46 3.51 3.54 3.56 3.55 3.57 3.61 3.71 3.80 3.92 3.99 4.06 3500*
4.02 4.06 4.12 4.20 4.30 4.22 4.32 4.42 4.53 4.64 4.55 4.40 4.20 4.32 4.38 3575*
4.37 4.24 4.13 4.14 4.20 4.25 4.32 4.35 4.31 4.27 4.25 4.27 4.31 4.36 4.41 3650*
4.52 4.59 4.71 4.79 4.81 4.73 4.61 4.42 4.20 4.06 4.00 3.88 3.86 3.92 3.98 3725*
```

Table A2. Listing of Data for LOWTRAN 3 (Cont)

4.12	4.18	4.31	4.37	4.42	4.50	4.53	4.58	4.59	4.61	4.61	4.59	4.53	4.49	4.44	3800
4.41	4.40	4.34	4.30	4.26	4.09	3.98	3.87	3.78	3.77	3.79	3.75	3.72	3.62	3.56	3875
3.51	3.49	3.32	3.19	3.07	2.96	2.87	2.30	2.68	2.53	2.59	2.51	2.59	2.57	2.30	3950
2.42	2.32	2.20	2.12	2.00	1.92	1.79	1.63	1.60	1.69	1.78	2.04	2.08	1.81	1.70	4025
1.63	1.61	1.60	1.49	1.14	1.35	1.64	1.69	1.70	1.59	1.45	1.29	1.19	1.08	1.02	4100
1.04	1.10	1.16	1.28	1.23	1.22	1.08	1.08	1.06	0.89	0.93	0.73	0.58	0.54	0.77	4175
0.81	0.74	0.71	0.57	0.49	0.43	0.38	0.12	0.18	0.20	0.41	0.37	0.31	0.31	-0.13	4250
-0.21	-0.32	-0.36	-0.39	-0.33	-0.39	-0.45	-0.50	-0.56	-0.62	-0.68	-0.77	-0.84	-0.91	-1.00	4325
-1.11	-1.19	-1.26	-1.31	-1.39	-1.43	-1.48	-1.52	-1.57	-1.60	-1.61	-1.60	-1.58	-1.51	-1.42	4400
-1.32	-1.26	-1.16	-1.00	-0.83	-0.71	-0.61	-0.52	-0.43	-0.36	-0.30	-0.21	-0.19	-0.17	-0.15	4475
-0.13	-0.17	-0.19	-0.12	-0.06	-0.01	0.00	-0.11	-0.23	-0.32	-0.44	-0.51	-0.48	-0.47	-0.42	4550
-0.48	-0.40	-0.39	-0.37	-0.35	-0.48	-0.75	-1.13	-1.58	-1.80	-1.66	-1.52	-1.35	-1.19	-1.02	4625
-0.88	-0.68	-0.65	-0.63	-0.62	-0.66	-0.73	-0.79	-0.88	-0.84	-0.70	-0.59	-0.43	-0.39	-0.58	4700
-0.61	-0.74	-0.79	-0.76	-0.69	-0.62	-0.59	-0.52	-0.48	-0.48	-0.42	-0.39	-0.38	-0.33	-0.29	4775
-0.26	-0.23	-0.22	-0.28	-0.37	-0.50	-0.60	-0.60	-0.51	-0.46	-0.42	-0.43	-0.45	-0.35	-0.24	4850
-0.14	-0.08	-0.08	0.00	0.11	0.32	0.43	0.42	0.32	0.23	0.22	0.29	0.45	0.55	0.52	4925
0.65	[illegible]	0.75	0.89	0.83	0.85	0.87	0.90	0.93	1.00	1.04	1.15	1.22	1.32	1.31	5000
1.32	1.33	1.48	1.78	1.87	2.01	1.92	1.86	1.89	1.92	1.98	2.03	2.39	2.31	2.48	5075
2.78	2.72	2.76	2.78	2.70	2.77	3.08	2.94	3.05	2.94	3.23	3.20	3.19	3.32	3.11	5150
3.41	3.31	3.36	3.46	3.36	3.39	3.50	3.41	3.22	3.19	2.98	2.78	2.98	3.02	2.92	5225
2.98	2.06	2.92	2.92	3.05	3.22	3.60	3.78	3.81	3.96	3.76	3.62	3.54	3.08	3.31	5300
3.16	3.37	3.41	3.30	3.33	3.53	3.51	3.40	3.43	3.52	3.31	3.40	3.58	3.61	3.49	5375
3.46	3.42	3.19	3.18	3.30	3.08	2.99	3.21	3.11	3.14	3.10	2.72	2.81	2.95	2.59	5450
2.73	2.72	2.47	2.51	2.60	2.42	2.37	2.73	1.91	1.87	1.81	1.78	1.53	1.51	1.32	5525
1.59	1.50	1.42	1.32	1.22	1.12	1.08	1.02	[illegible]	0.92	0.90	0.87	0.84	0.82	0.79	5600
0.78	0.76	0.75	0.72	0.71	0.71	0.70	0.69	0.67	0.61	0.59	0.52	0.48	0.41	0.39	5675
0.38	0.33	0.32	0.30	0.30	0.30	0.29	0.28	0.27	0.26	0.25	0.23	0.22	0.21	0.20	5750
0.18	0.14	0.13	0.06	0.01	-0.03	-0.07	-0.11	-0.16	-0.21	-0.24	-0.29	-0.32	-0.38	-0.41	5825
-0.45	-0.50	-0.54	-0.61	-0.69	-0.76	-0.84	-0.90	-0.97	-1.01	-1.10	-1.13	-1.19	-1.22	-1.26	5900
-1.30	-1.33	-1.36	-1.39	-1.43	-1.48	-1.50	-1.52	-1.57	-1.61	-1.66	-1.70	-1.72	-1.78	-1.91	5975
-1.89	-1.92	-2.00	-2.09	-2.16	-2.24	-2.31	-2.40	-2.48	-2.54	-2.61	-2.71	-2.83	-2.95	-3.10	6050
-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	6125
-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	6200
-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	6275
-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	6350
-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	6425
-3.78	-3.33	-3.01	-2.82	-2.68	-2.49	-2.30	-2.13	-2.00	-1.81	-1.60	-1.61	[illegible]	-0.99	-0.79	6500
-0.63	-0.48	-0.36	-0.28	-0.16	-0.06	0.08	0.20	0.28	0.41	0.54	0.69	0.80	0.92	1.34	6575
1.19	1.19	[illegible]	0.99	1.02	1.19	1.29	1.30	1.29	1.38	1.19	1.39	1.42	1.43	1.70	6650
1.62	1.54	1.41	1.53	1.86	1.96	1.97	2.02	2.01	1.94	1.94	1.83	2.03	2.21	2.42	6725
2.30	2.16	2.02	2.02	2.02	2.13	1.90	1.71	2.01	1.56	1.56	1.51	1.30	1.63	1.54	6800
1.67	1.78	2.22	2.39	2.38	2.30	1.93	2.39	2.49	2.52	2.57	2.21	2.19	2.40	2.41	6875
2.45	2.51	2.23	2.49	2.30	2.61	2.72	2.52	2.63	2.56	2.51	2.70	2.62	2.62	2.90	6950
2.74	2.79	2.74	2.70	2.88	2.81	2.72	2.76	2.84	2.92	2.98	2.83	2.86	3.02	3.08	7025
3.26	3.03	3.14	3.29	3.03	3.11	3.15	3.30	3.31	3.22	3.30	3.06	3.34	3.40	3.37	7100
3.32	3.08	3.09	3.09	3.01	3.07	3.07	[illegible]	3.21	[illegible]	3.67	3.59	3.79	3.70	3.69	7175
3.39	3.11	3.13	3.01	3.10	3.01	3.18	3.32	3.43	[illegible]	3.40	3.39	3.39	3.51	3.54	7250
3.42	3.58	3.67	3.59	3.63	3.66	3.48	3.39	3.29	3.31	3.41	3.23	3.32	3.12	2.91	7325
2.91	2.75	2.78	2.72	2.62	2.58	2.32	2.22	2.08	1.97	1.68	1.62	1.64	1.53	1.56	7400
1.51	1.52	1.48	1.42	1.42	1.40	1.41	1.43	1.56	1.52	1.51	1.52	1.39	1.39	1.30	7475
1.09	1.16	1.21	1.20	1.22	1.20	1.18	1.20	1.19	1.17	1.10	1.10	1.09	1.10	1.11	7550
1.04	0.98	0.90	0.85	0.93	0.90	0.90	0.86	0.71	0.79	0.70	0.71	0.67	0.62	0.53	7625
0.42	0.31	0.20	0.01	-0.08	-0.17	-0.26	-0.35	-0.44	-0.53	-0.63	-0.73	-0.83	-0.93	-1.04	7700
-1.14	-1.24	-1.34	-1.44	-1.54	-1.64	-1.74	-1.84	-1.94	-2.04	-2.14	-2.24	-2.34	-2.44	-2.54	7775
-2.64	-2.74	-2.84	-2.94	-3.04	-3.14	-3.24	-3.34	-3.44	-3.54	-3.64	-3.74	-3.84	-3.94	-4.34	7850
-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	7925
-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	8000
-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	8075
-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	8150
-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	8225
-4.15	-4.06	-3.97	-3.88	-3.79	-3.70	-3.61	-3.52	-3.43	-3.34	-3.25	-3.16	-3.07	-2.98	-2.89	8300

SPECTRAL DATA: H_2O

Table A2. Listing of Data for LOWTRAN 3 (Cont)

```
-2.80-2.71-2.62-2.53-2.44-2.35-2.26-2.18-2.09-2.00-1.91-1.82-1.73-1.64-1.55 8375
-1.46-1.37-1.28-1.19-1.10-1.01-0.92-0.83-0.74-0.65-0.56-0.47-0.38-0.29-0.20 8450
-0.14-0.09-0.02 0.03 0.10 0.17 0.22 0.30 0.35 0.41 0.45 0.42 0.40 0.43 0.46 8525
 0.50 0.55 0.71 0.84 0.93 1.01 1.06 1.07 1.02 1.01 1.12 1.23 1.24 1.28 1.34 8600
 1.43 1.52 1.56 1.59 1.56 1.51 1.61 1.50 1.70 1.82 1.32 1.34 1.89 1.81 1.45 8675
 1.30 1.28 1.63 1.50 1.49 1.55 1.40 1.32 1.39 1.53 1.82 2.23 2.61 2.51 2.23 8750
 1.66 1.61 1.19 1.32 1.52 1.70 1.90 2.01 1.92 1.91 2.12 2.10 2.01 2.18 1.39 8825
 2.11 2.28 2.21 2.13 2.00 1.91 1.92 1.97 1.88 1.91 1.91 1.92 1.93 1.74 1.51 8900
 1.50 1.27 1.20 1.18 1.11 0.99 0.86 0.71 0.60 0.44 0.31 0.19 0.03-0.07-0.21 8975
-0.35-0.49-0.64-0.79-0.94-1.11-1.24-1.41-1.57-1.73-1.91-2.09-2.27-2.45-2.53 9050
-2.81-2.99-3.18-3.37-3.56-3.75-3.94-4.13-4.31-4.49-4.66-4.83-4.99-5.14-5.28 9125
-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-4.60-4.26-3.89-3.57-3.32-3.11-2.91 9875
-2.89-2.79-2.74-2.63-2.47-2.29-2.20-2.17-2.23-2.27-2.32-2.12-2.00-2.07-2.37 9950
-2.07-1.90-1.77-1.70-1.63-1.60-1.59-1.43-1.21-1.15-1.09-1.13-1.29-1.19-0.3810025
-0.93-0.87-0.91-0.89-0.71-0.62-0.59-0.58-0.63-0.58-0.39-0.22-0.14-0.06-0.3110100
-0.01-0.00-0.20-0.16-0.02 0.18 0.32 0.42 0.37 0.23 0.12 0.15 0.28 0.43 0.5910175
 0.58 0.53 0.44 0.39 0.38 0.35 0.23 0.26 0.19 0.08 0.10 0.19 0.27 0.39 0.6310250
 0.32 0.37 0.58 0.64 0.87 0.98 1.00 1.02 1.13 1.08 1.08 1.16 1.16 1.30 1.4110325
 1.40 1.32 1.32 1.37 1.42 1.50 1.42 1.30 1.36 1.38 1.49 1.63 1.62 1.62 1.7010400
 1.60 1.60 1.56 1.56 1.63 1.64 1.56 1.49 1.49 1.52 1.58 1.62 1.62 1.61 1.5110475
 1.62 1.63 1.71 1.72 1.70 1.70 1.67 1.62 1.66 1.70 1.67 1.56 1.49 1.42 1.3810550
 1.26 1.20 1.13 1.14 1.19 1.29 1.50 1.72 1.86 1.70 1.82 1.88 1.82 1.89 1.3910625
 2.08 2.14 2.04 2.02 2.02 1.98 1.90 1.83 1.81 1.72 1.69 1.59 1.50 1.36 1.2010700
 0.98 0.63 0.43 0.29 0.16 0.05 0.02 0.03 0.03 0.01-0.08-0.18-0.23-0.11-0.0610775
-0.03-0.14-0.21-0.08-0.06 0.10 0.18 0.11 0.32 0.42 0.44 0.38 0.28 0.42 0.4310850
 0.41 0.33 0.32 0.41 0.50 0.46 0.31 0.18 0.08 0.20 0.21 0.34 0.36 0.29 0.3510925
 0.39 0.42 0.38 0.32 0.30 0.16-0.01-0.23-0.41-0.52-0.48-0.53-0.61-0.45-0.2311000
-0.03 0.21 0.36 0.39 0.47 0.44 0.40 0.51 0.59 0.53 0.69 0.57 0.48 0.52 0.6211075
 0.59 0.55 0.50 0.32 0.26 0.11-0.08-0.10-0.16-0.43-0.62-0.88-1.09-1.16-1.3111150
-1.45-1.49-1.78-1.91-2.01-1.97-1.97-1.97-1.97-2.26-2.20-2.01-1.99-2.00-2.0411225
-2.37-2.49-2.44-2.36-2.32-2.19-2.10-2.25-2.16-2.36-2.44-2.40-2.49-2.46-2.4311300
-2.40-2.36-2.40-2.49-2.59-2.68-2.89-3.28-3.51-3.74-3.97-4.20-4.43-4.66-4.5911375
-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.0011450
-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.0011525
-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.0011600
-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.0011675
-3.71-3.56-3.40-3.21-3.06-2.90-2.74-2.60-2.46-2.32-2.17-2.03-1.87-1.79-1.7411750
-1.83-1.82-1.71-1.59-1.49-1.46-1.46-1.49-1.49-1.25-1.24-1.08-0.90-1.06-0.9111825
-0.91-1.01-0.99-0.87-0.92-0.79-0.42-0.54-0.38-0.42-0.48-0.34-0.27-0.17-0.2811900
-0.30-0.22-0.30-0.09-0.01-0.20 0.06 0.10 0.06 0.14-0.12-0.02-0.02-0.13-0.1111975
-0.10-0.06-0.05-0.04-0.10-0.04-0.06-0.21-0.38-0.61-0.40-0.31-0.42-0.58-0.5712050
-0.54-0.24 0.11 0.51 0.81 0.79 0.62 0.26-0.31-0.67-0.80-0.88-0.58-0.39-0.1012125
 0.09 0.06 0.08 0.16 0.21 0.13 0.32 0.35 0.51 0.60 0.51 0.51 0.40 0.40 0.4312200
 0.42 0.33 0.43 0.34 0.22 0.13-0.11-0.31-0.31-0.41-0.41-0.39-0.53-0.69-0.3412275
-0.88-1.01-1.10-1.13-1.29-1.45-1.49-1.67-1.67-1.51-1.66-1.60-1.69-1.83-1.5812350
-1.42-1.40-1.24-1.38-1.31-1.30-1.30-1.28-1.39-1.33-1.40-1.35-1.37-1.39-1.4112425
-1.49-1.48-1.56-1.47-1.46-1.41-1.42-1.40-1.41-1.31-1.15-1.13-1.20-1.41-1.8812500
-2.08-2.08-2.22-2.35-2.35-1.98-1.92-1.70-1.57-1.69-1.70-1.70-1.66-1.84-1.5012575
-1.56-1.42-1.29-1.39-1.20-1.60-1.50-1.44-1.53-1.40-1.45-1.58-1.58-1.69-1.7912650
-2.00-2.16-1.99-2.23-2.04-2.04-2.39-2.74-3.09-3.44-3.79-4.14-4.49-4.84-5.2912725
-2.46-2.26-1.99-2.01-2.16-2.31-2.15-2.01-1.99-2.14-2.41-2.12-1.99-1.84-1.7913400
-1.71-1.78-1.72-1.68-1.78-1.52-1.36-1.29-1.22-0.91-0.90-1.01-0.76-0.90-0.9013475
-0.98-1.19-1.00-0.79-0.68-0.60-0.73-0.95-0.85-0.61-0.61-0.43-0.51-0.97-0.9313550
-0.61-0.41-0.29-0.29-0.61-0.76-0.19-0.18 0.    0.19-0.18 0.20 0.20 0.02  .2013625
-0.91 0.10 0.29 0.11 0.   -0.37-0.10 0.02 0.16 0.20 0.    0.09 0.09 0.09 0.0713700
 0.22 0.11 0.11 0.21 0.09 0.21 0.20 0.37 0.28 0.07 0.09-0.29-0.69-0.69-0.7413775
-0.00-1.01-0.06-0.54-0.19 0.19 0.23 0.21 0.29 0.20 0.29 0.52 0.54 0.51  .6013850
 0.40 0.49 0.40 0.46 0.49 0.27 0.06-0.33-0.81-1.17-1.11-1.37-1.52-1.54-1.9413925
-2.06-2.06-2.14-1.96-2.00-2.00-2.00-2.23-2.31-2.31-2.53-2.31-2.31-2.31-2.2814000
-2.34-2.34-1.91-1.82-1.69-1.56-1.84-1.91-1.75-1.83-1.76-1.54-1.90-1.80-1.6814075
-1.69-1.56-1.60-1.71-1.36-1.36-1.46-1.40-1.40-1.40-1.36-1.45-1.49-1.85-1.3914150
```

SPECTRAL DATA: H_2O

SPECTRAL DATA: H_2O cont.

-1.23	-1.18	-1.19	-1.34	-1.36	-1.23	-1.23	-1.37	-1.30	-1.41	-1.28	-1.27	-1.37	-1.32	-1.32	14225
-1.22	-1.28	-1.38	-1.63	-2.07	-2.42	-2.58	-2.59	-2.88	-2.54	-2.43	-1.88	-1.60	-1.26	-1.16	14300
-1.23	-1.18	-1.23	-1.10	-0.83	-0.80	-0.80	-0.90	-0.98	-0.97	-0.97	-0.91	-0.92	-1.13	-1.24	14375
-1.50	-1.89	-2.18	-2.32	-2.63	-3.91	-4.20	-4.49	-4.78	-5.07	-5.37	-5.07	-5.07	-5.07	-5.07	14450
-4.95	-3.70	-3.20	-2.75	-1.90	-1.73	-1.51	-1.29	-1.11	-0.91	-0.71	-0.51	-0.30	-0.06	0.22	500
0.49	0.76	1.08	1.23	1.56	1.76	1.91	2.08	2.23	2.36	2.51	2.72	2.90	3.12	3.37	575
3.56	3.69	3.79	3.86	3.88	3.86	3.73	3.58	3.38	3.17	2.86	2.73	2.52	2.31	2.17	650
2.01	1.89	1.77	1.63	1.47	1.21	0.92	0.53	0.23	-0.17	-0.53	-0.74	-0.81	-0.84	-0.98	725
-1.08	-1.18	-1.42	-1.61	-1.86	-2.10	-2.29	-2.51	-2.72	-2.91	-3.14	-5.00	-5.00	-5.00	-5.00	800
-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-2.68	-2.47	-2.19	-1.97	-1.71	-1.50	-1.32	-1.21	-1.13	875
-1.09	-1.11	-1.10	-1.09	-1.01	-1.01	-1.11	-1.33	-1.66	-2.13	-2.51	-2.83	-2.71	-2.39	-2.19	950
-1.78	-1.59	-1.33	-1.19	-1.01	-0.96	-0.91	-0.90	-0.87	-0.80	-0.79	-0.86	-1.07	-1.28	-1.69	1025
-2.11	-2.74	-3.09	-3.50	-3.03	-2.58	-2.23	-1.89	-1.54	-1.28	-1.13	-1.11	-1.16	-1.29	-1.23	1100
-1.21	-1.17	-1.12	-1.15	-1.19	-1.20	-1.17	-1.02	-0.89	-0.68	-0.42	-0.24	-0.01	0.18	0.40	1175
0.57	0.77	0.96	1.07	1.13	1.11	1.08	1.15	1.27	1.33	1.44	1.40	1.13	0.89	0.53	1250
0.54	0.65	0.78	0.81	0.86	0.82	0.68	0.47	0.14	-0.12	-0.48	-0.92	-1.43	-1.89	-2.32	1325
-2.81	-5.00	-5.00	-5.00	-3.14	-2.47	-2.00	-1.71	-1.59	-1.61	-1.69	-1.82	-1.87	-1.90	-1.94	1400
-2.04	-2.10	-2.23	-2.32	-2.48	-2.71	-2.88	-3.09	-2.99	-2.43	-2.00	-1.69	-1.42	-1.39	-1.49	1475
-1.78	-2.01	-2.41	-2.64	-2.63	-2.49	-2.38	-2.27	-2.16	-2.04	-1.94	-1.63	-1.76	-1.71	-1.78	1550
-1.72	-1.81	-1.92	-2.03	-2.27	-2.61	-3.21	-4.01	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	1625
-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	1700
-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-4.30	-3.42	-3.17	-2.98	1775
-2.83	-2.71	-2.67	-2.67	-2.68	-2.58	-2.33	-2.01	-1.64	-1.32	-0.97	-0.76	-0.63	-0.59	-0.50	1850
-0.63	-0.69	-0.87	-1.05	-1.26	-1.53	-1.87	-1.91	-1.93	-2.02	-2.21	-2.48	-2.80	-3.08	-3.11	1925
-3.09	-2.93	-2.76	-2.39	-2.01	-1.69	-1.36	-0.99	-0.63	-0.28	0.00	0.08	0.11	0.12	0.12	2000
0.07	0.01	-0.08	-0.23	-0.40	-0.51	-0.53	-0.57	-0.60	-0.61	-0.73	-0.81	-0.95	-1.05	-1.32	2075
-0.91	-0.68	-0.41	-0.03	0.19	0.41	0.76	1.00	1.18	1.39	1.51	1.58	1.68	1.71	1.93	2150
1.91	2.02	2.18	2.32	2.50	2.61	2.69	2.81	2.89	2.96	3.04	3.14	3.27	3.41	3.55	2225
3.72	3.90	4.03	4.22	4.42	4.61	4.71	4.73	4.65	4.63	4.72	4.78	4.79	4.50	3.62	2300
3.28	2.79	2.30	1.85	1.35	0.62	-0.24	-1.69	-2.18	-2.01	-1.79	-1.53	-1.32	-1.20	-1.15	2375
-1.12	-1.19	-1.25	-1.26	-1.20	-1.17	-1.28	-1.32	-1.54	-1.84	-2.16	-2.30	-2.26	-2.01	-1.71	2450
-1.36	-1.06	-0.81	-0.61	-0.49	-0.45	-0.47	-0.49	-0.46	-0.37	-0.31	-0.34	-0.49	-0.73	-1.11	2525
-1.43	-2.01	-2.60	-2.89	-2.87	-2.74	-2.51	-2.42	-2.38	-2.39	-2.42	-2.46	-2.48	-2.49	-2.63	2600
-2.49	-2.46	-2.53	-2.69	-2.74	-2.82	-2.87	-2.83	-2.82	-2.79	-2.71	-2.66	-2.49	-2.40	-2.32	2675
-2.26	-2.23	-2.20	-2.09	-2.02	-1.96	-1.85	-1.94	-1.86	-1.66	-1.57	-1.83	-1.79	-1.73	-1.59	2750
-1.64	-1.69	-1.74	-1.79	-1.87	-1.78	-1.63	-1.50	-1.37	-1.21	-1.00	-0.83	-0.69	-0.53	-0.41	2825
-0.30	-0.19	-0.09	-0.04	0.02	0.10	0.16	0.18	0.23	0.26	0.27	0.26	0.24	0.22	0.17	2900
0.12	0.07	-0.01	-0.07	-0.09	0.32	0.72	0.91	1.12	1.03	0.67	0.17	-0.11	-0.39	-0.29	2975
-0.17	-0.08	-0.00	0.03	0.13	0.18	0.24	0.27	0.29	0.30	0.29	0.26	0.23	0.21	0.13	3050
0.09	0.02	-0.04	-0.19	-0.32	-0.51	-0.72	-0.98	-1.18	-1.50	-1.62	-1.81	-2.04	-2.29	-2.49	3125
-2.62	-2.87	-3.03	-3.21	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	3200
-5.00	-4.01	-3.38	-3.01	-2.63	-2.32	-2.09	-1.98	-1.94	-2.00	-2.14	-2.26	-2.20	-2.02	-1.82	3275
-1.59	-1.43	-1.39	-1.45	-1.64	-1.90	-2.09	-2.54	-2.91	-3.28	-3.61	-3.72	-3.64	-3.50	-3.41	3350
-3.37	-3.30	-3.16	-3.01	-2.76	-2.51	-2.20	-1.80	-1.49	-1.22	-0.97	-0.72	-0.49	-0.20	0.03	3425
0.20	0.36	0.51	0.61	0.67	0.83	1.00	1.22	1.38	1.56	1.70	1.86	2.01	2.20	2.31	3500
2.47	2.61	2.76	2.92	3.01	3.05	3.02	2.98	2.98	3.01	3.03	2.97	2.78	2.44	2.13	3575
1.83	1.59	1.49	1.50	1.67	1.94	2.22	2.50	2.71	2.93	3.12	3.19	3.17	3.15	3.21	3650
3.26	3.19	2.98	2.59	2.14	1.70	1.22	0.55	-0.27	-1.09	-2.54	-3.03	-2.94	-2.73	-2.53	3725
-2.61	-2.60	-2.63	-2.60	-2.57	-2.53	-2.57	-2.64	-2.77	-3.04	-3.38	-3.98	-5.00	-5.00	-5.00	3800
-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	3875
-5.00	-4.00	-3.73	-3.62	-3.59	-3.53	-3.56	-3.57	-3.53	-3.51	-3.45	-3.37	-3.26	-3.21	-3.18	3950
-3.27	-3.36	-3.60	-3.95	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	4025
-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-4.52	4100
-4.07	-3.89	-3.76	-3.67	-3.56	-3.42	-3.35	-3.26	-3.18	-3.14	-3.11	-3.09	-3.10	-3.12	-3.23	4175
-3.30	-3.38	-3.37	-3.29	-3.14	-3.08	-3.00	-2.93	-2.89	-2.91	-3.06	-3.08	-3.16	-3.31	-3.48	4250
-3.71	-3.98	-5.00	-5.00	-5.00	-5.00	-4.52	-3.98	-3.69	-3.42	-3.18	-2.95	-2.77	2.61	-2.48	4325
-2.41	-2.41	-2.48	-2.38	-2.34	-2.27	-2.21	-2.31	-2.48	-2.73	-3.21	-4.13	-5.00	-5.00	-5.00	4400
-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	4475
-5.00	-5.00	-4.13	-4.02	-3.99	-3.96	-3.87	-3.73	-3.51	-3.29	-3.13	-2.99	-2.84	-2.73	-2.59	4550
-2.68	-2.69	-2.65	-2.62	-2.59	-2.57	-2.62	-2.81	-3.04	-3.21	-3.39	-3.42	-3.36	-3.21	-3.13	4625
-2.93	-2.80	-2.64	-2.52	-2.37	-2.28	-2.20	-2.13	-2.07	-2.02	-1.96	-1.85	-1.78	-1.63	-1.44	4700

SPECTRAL DATA: UNIFORMLY MIXED GASES

Table A2. Listing of Data for LOWTRAN 3 (Cont)

SPECTRAL DATA: UNIFORMLY MIXED GASES

-1.31	-1.20	-1.08	-0.99	-0.96	-0.86	-0.76	-0.52	-0.31	-0.06	0.13	0.30	0.37	0.36	0.36	4775
0.35	0.35	0.39	0.46	0.48	0.61	0.23	-0.08	-0.38	-0.67	-0.88	-0.96	-0.98	-0.87	-0.57	4850
-0.36	-0.12	0.14	0.44	0.68	0.90	1.11	1.19	1.24	1.25	1.26	1.27	1.51	1.59	1.50	4925
1.78	0.71	0.11	-0.29	-0.67	-1.32	-1.61	-1.58	-1.42	-1.18	-0.91	-0.59	-0.27	-0.05	0.29	5000
0.57	0.73	0.92	0.81	0.73	0.79	0.91	1.01	1.03	0.86	0.72	0.63	0.38	0.12	-0.21	5075
-0.47	-0.67	-1.23	-1.67	-2.31	-2.76	-3.24	-3.49	-3.51	-3.47	-3.39	-3.37	-3.43	-3.53	-3.50	5150
-3.36	-3.18	-3.07	-2.96	-3.08	-3.14	-3.12	-3.23	-3.07	-2.83	-2.47	-2.25	-2.07	-1.91	-1.78	5225
-1.63	-1.46	-1.27	-1.23	-1.26	-1.40	-1.57	-1.98	-2.28	-2.87	-3.74	-5.00	-5.00	-5.00	-5.00	5300
-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	5375
-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	5450
-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	5525
-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	5600
-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	5675
-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	5750
-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	5825
-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-4.91	-4.79	-4.51	5900
-4.48	-4.40	-4.29	-4.17	-3.90	-3.77	-3.59	-3.62	-3.72	-3.73	-3.69	-3.31	-3.12	-2.91	-2.53	5975
-2.41	-2.27	-2.16	-2.11	-2.28	-2.29	-2.21	-2.06	-1.91	-1.99	-2.27	-2.59	-2.96	-3.35	-3.59	6050
-3.79	-3.68	-3.53	-3.45	-3.39	-3.31	-3.18	-2.97	-2.69	-2.39	-2.11	-1.83	-1.59	-1.49	-1.22	6125
-1.08	-0.59	-0.68	-0.54	-0.71	-0.79	-0.78	-0.66	-0.49	-0.54	-0.86	-1.37	-2.08	-2.44	-3.46	6200
-3.72	-3.74	-3.59	-3.22	-2.95	-2.52	-2.21	-1.64	-1.34	-1.09	-0.86	-0.72	-0.61	-0.70	-0.72	6275
-0.57	-0.57	-0.38	-0.51	-0.97	-1.36	-1.89	-2.76	-3.18	-4.21	-4.57	-4.62	-4.78	-4.87	-5.00	6350
-5.00	-5.00	-5.00	-5.00	-5.00	-4.93	-4.46	-3.99	-3.45	-2.99	-2.63	-2.30	-2.09	-2.02	-2.12	6425
-2.18	-2.13	-2.04	-1.79	-1.83	-2.08	-2.28	-2.81	-3.01	-3.15	-3.22	-3.29	-3.58	-3.89	-4.46	6500
-4.89	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	6575
-4.81	-4.52	-4.11	-3.63	-3.09	-2.99	-2.91	-2.99	-3.19	-3.20	-3.36	-3.62	-3.89	-3.92	-3.73	6650
-3.53	-3.37	-3.19	-3.07	-2.79	-2.52	-2.36	-2.24	-2.19	-2.32	-2.41	-2.27	-2.86	-2.81	-2.15	6725
-2.47	-2.91	-3.57	-4.89	-5.00	-5.00	-5.00	-5.00	-5.00	-4.61	-4.18	-3.89	-3.57	-3.33	-3.32	6800
-2.74	-2.51	-2.28	-1.99	-1.73	-1.57	-1.38	-1.21	-1.11	-0.98	-0.87	-0.79	-0.60	-0.37	-0.18	6875
-0.04	-0.04	-0.06	-0.15	-0.18	-0.19	-0.23	-0.45	-1.02	-1.97	-2.78	-3.71	-4.01	-4.20	-4.35	6950
-4.58	-4.73	-4.81	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	7025
-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	7100
-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	7175
-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	7250
-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	7325
-5.00	-5.00	-5.00	-4.71	-4.31	-3.99	-3.68	-3.50	-3.34	-3.22	-3.23	-3.25	-3.24	-3.18	-3.10	7400
-3.07	-3.18	-3.41	-3.67	-4.12	-4.68	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-4.51	-4.18	7475
-3.73	-3.48	-3.17	-2.95	-2.73	-2.63	-2.58	-2.59	-2.57	-2.49	-2.42	-2.39	-2.48	-2.62	-3.02	7550
-3.49	-4.16	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-4.87	-4.50	7625
-4.21	-3.90	-3.66	-3.56	-3.51	-3.51	-3.51	-3.49	-3.41	-3.34	-3.34	-3.47	-3.60	-3.87	-4.23	7700
-4.59	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-4.93	7775
-4.51	-4.10	-3.78	-3.32	-3.03	-2.74	-2.43	-2.08	-1.83	-1.59	-1.29	-1.02	-0.81	-0.70	-0.73	7850
-0.90	-1.09	-1.19	-1.35	-1.47	-1.57	-1.66	-1.80	-1.91	-2.04	-2.18	-2.33	-2.47	-2.61	-2.78	7925
-2.97	-3.10	-3.29	-3.44	-3.63	-3.81	-3.98	-4.15	-4.32	-4.61	-4.71	-4.83	-5.00	-5.00	-5.00	8000
-5.00	-5.00	-5.00	-5.00	-4.32	-3.24	-2.59	-2.12	-1.62	-1.57	-1.34	-1.15	-1.02	-0.82	-0.64	12950
-0.48	-0.33	-0.14	-0.06	0.08	0.21	0.39	0.52	0.61	0.72	0.85	0.96	1.02	1.12	1.18	13025
1.21	1.17	1.08	0.99	0.90	0.97	1.13	1.37	1.58	1.74	1.70	1.49	1.17	0.73	0.22	13100
-0.51	-1.57	-3.49	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	13175

SPECTRAL DATA: OZONE

-4.15	-3.51	-3.00	-2.54	-2.12	-1.76	-1.50	-1.21	-0.86	-0.49	-0.29	-0.13	0.02	0.12	0.24	575
0.32	0.43	0.52	0.59	0.65	0.72	0.79	0.76	0.72	0.68	0.64	0.68	0.79	0.83	0.93	650
0.80	0.78	0.68	0.56	0.49	0.42	0.34	0.26	0.14	0.02	-0.14	-0.35	-0.51	-0.74	-0.98	725
-1.17	-1.40	-1.58	-2.11	-2.47	-2.83	-3.24	-3.59	-3.94	-5.00	-5.00	-5.00	-5.00	-5.00	-5.0	800
-5.00	-5.00	-5.00	-5.00	-5.00	-4.46	-4.08	-3.50	-3.14	-2.78	-2.41	-2.10	-1.78	-1.49	-1.23	875
-0.20	0.15	0.35	0.57	0.70	0.95	1.20	1.40	1.65	1.80	1.97	2.10	2.21	2.31	2.38	950*
2.40	2.42	2.58	2.52	2.20	2.48	2.56	2.45	2.30	2.00	1.20	0.95	0.92	0.93	0.90	1025*
0.89	0.90	0.92	0.96	0.95	0.96	0.95	0.90	0.80	0.65	0.55	0.40	0.30	0.19	0.09	1100*
-0.02	-0.11	-0.22	-0.41	-0.56	-0.71	-0.89	-1.03	-1.18	-1.33	-1.60	-1.76	-1.90	-2.02	-2.21	1175
-2.46	-2.59	-2.79	-3.00	-3.22	-3.61	-4.16	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	1250
-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	1325
-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	1400
-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00	1475

Table A2. Listing of Data for LOWTRAN 3 (Cont)

```
-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-4.16-3.91-3.60-3.41-3.05-2.69 1550
-2.44-2.19-2.03-1.86-1.71-1.56-1.48-1.39-1.26-1.13-.97-0.81-0.65-0.48-0.35 1625
-0.22-0.14-0.06-0.02-0.59-0.18-0.14 0.06 0.26-0.02-0.42-0.60-0.82-0.90-0.74 1700
-0.74-0.79-0.84-0.09-0.85-0.81-0.76-0.70-0.68-0.64-0.65-0.66-0.72-0.78-0.94 1775
-0.98-1.02-1.14-1.24-1.33-1.47-1.61-1.77-1.92-1.96-2.04-2.04-2.09-2.06-2.03 1850
-1.98-1.93-1.87-1.82-1.76-1.71-1.65-1.59-1.51-1.44-1.36-1.24-1.18-1.04-0.98 1925
-0.88-0.78-0.69-0.59-0.49-0.37-0.25-0.18-0.10 0.00 0.16 0.27 0.39 0.57 0.75 2000
 0.93 1.11 1.20 1.33 1.44 1.46 1.48 1.48 1.64 1.58 1.49 1.23 0.66 0.38-0.33 2075
-0.71-0.66-0.58-0.49-0.44-0.40-0.40-0.46-0.53-0.64-0.76-0.83-1.01-1.14-1.26 2150
-1.48-1.55-1.69-1.83-1.98-2.13-2.20-2.45-2.64-2.86-3.07-3.24-3.50-3.72-3.94 2225
-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00 2300
-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00 2375
-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00 2450
-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00 2525
-5.00-5.00-5.00-5.00-5.00-5.00-5.00-5.00-4.16-3.97-3.77-3.58-3.38-3.07-2.75 2600
-2.44-2.12-1.85-1.57-1.30-1.07-0.98-0.94-0.89-0.85-0.81-0.77-0.72-0.69-0.63 2675
-0.58-0.53-0.48-0.41-0.35-0.26-0.19-0.17-0.18-0.19-0.46-0.79-1.12-1.45-1.75 2750
-2.38-2.97-3.57-4.15-5.00-5.00-5.00-4.16-3.90-3.63-3.37-3.10-2.79-2.47-2.15 2825
-1.94-1.73-1.63-1.52-1.41-1.33-1.25-1.17-1.09-1.02-0.96-0.83-0.82-0.73-0.63 2900
-0.54-0.42-0.27-0.12 0.03 0.18 0.25 0.31 0.39 0.47 0.48 0.49 0.50 0.52 0.40 2975
 0.46 0.23 0.01-0.11-0.33-0.55-0.77-0.83-0.88-0.94-0.92-0.91-0.90-0.85-0.80 3050
-0.76-0.71-0.69-0.67-0.66-0.65-0.65-0.66-0.67-0.69-0.70-0.72-0.82-0.93-1.03 3125
-1.14-1.24-1.34-1.51-1.65-2.13-2.57-2.92-3.26-3.71-4.16-5.00-5.00-5.00-5.00 3200
 2.93E-04 3.86E-04 5.09E-04 6.56E-04 8.85E-04 1.06E-03 1.31E-03 1.73E-03     2050
 2.27E-03 2.73E-03 3.36E-03 3.95E-03 5.46E-03 7.19E-03 9.00E-03 1.13E-02     2120
 1.36E-02 1.66E-02 1.96E-02 2.16E-02 2.36E-02 2.63E-02 2.90E-02 3.15E-02     2160
 3.40E-02 3.66E-02 3.92E-02 4.26E-02 4.60E-02 4.95E-02 5.30E-02 5.65E-02     2200
 6.00E-02 6.30E-02 6.60E-02 6.89E-02 7.15E-02 7.39E-02 7.60E-02 7.84E-02     2240
 8.08E-02 8.39E-02 8.70E-02 9.17E-02 9.56E-02 1.04E-01 1.20E-01 1.39E-01     2280
 1.52E-01 1.60E-01 1.69E-01 1.67E-01 1.51E-01 1.37E-01 1.23E-01 1.18E-01     2320
 1.16E-01 1.14E-01 1.12E-01 1.12E-01 1.11E-01 1.11E-01 1.12E-01 1.14E-01     2360
 1.13E-01 1.12E-01 1.09E-01 1.07E-01 1.02E-01 9.90E-02 9.50E-02 9.00E-02     2400
 8.65E-02 8.29E-02 7.65E-02 7.05E-02 6.50E-02 6.10E-02 5.50E-02 4.95E-02     2440
 4.50E-02 4.00E-02 3.75E-02 3.50E-02 3.10E-02 2.65E-02 2.50E-02 2.20E-02     2480
 1.95E-02 1.75E-02 1.60E-02 1.40E-02 1.20E-02 1.05E-02 9.50E-03 9.00E-03     2520
 8.00E-03 7.00E-03 6.50E-03 6.00E-03 5.50E-03 4.75E-03 4.20E-03 3.75E-03     2560
 3.50E-03 3.00E-03 2.50E-03 2.25E-03 2.00E-03 1.85E-03 1.70E-03 1.60E-03     2600
 1.50E-03 1.50E-03 1.54E-03 1.50E-03 1.47E-03 1.34E-03 1.25E-03 1.06E-03     2640
 9.06E-04 7.57E-04 6.41E-04 5.09E-04 4.04E-04 3.36E-04 2.86E-04 2.32E-04     2680
 1.94E-04 1.57E-04 1.31E-04 1.02E-04 5.07E-05                                2720
26.7 20.7 14.8 11.7  9.02 7.68 6.68 5.68 5.34 5.34 5.34 5.34 3.56 1.78 0.00  700
 4.50E-03 8.00E-03 1.07E-02 1.10E-02 1.27E-02 1.71E-02 2.00E-02 2.45E-02    13000
 3.07E-02 3.84E-02 4.78E-02 5.67E-02 6.54E-02 7.62E-02 9.15E-02 1.00E-01    14600
 1.09E-01 1.20E-01 1.28E-01 1.12E-01 1.11E-01 1.16E-01 1.19E-01 1.13E-01    16200
 4.06E-02 3.87E-02 3.62E-02 2.94E-02 2.09E-02 1.80E-02 1.91E-02 1.66E-02    19400
 1.03E-01 9.24E-02 8.20E-02 7.57E-02 7.07E-02 6.58E-02 5.56E-02 4.77E-02    17800
 1.17E-02 7.70E-03 6.10E-03 5.50E-03 5.10E-03 3.70E-03 3.20E-03 3.10E-03    21000
 2.55E-03 1.98E-03 1.40E-03 9.25E-04 2.50E-04 0.00E-04 0.00E-04 0.00E-04    22600
 5.65E-04 2.04E-03 7.35E-03 2.03E-02 4.98E-02 1.18E-01 2.46E-01 5.18E-01    27600
 1.02E-00 1.95E-00 3.79E-00 6.65E-00 1.24E+01 2.20E+01 3.67E+01 5.95E+01    31600
 8.50E+01 1.26E+02 1.68E+02 2.06E+02 2.42E+02 2.71E+02 2.91E+02 3.02E+02    35600
 3.03E+02 2.94E+02 2.77E+02 2.54E+02 2.26E+02 1.91E+02 1.68E+02 1.44E+02    39600
 1.17E+02 9.75E+01 7.65E+01 6.74E+01 4.62E+01 3.46E+01 2.52E+01 2.03E+01    43600
 1.57E+01 1.20E+01 1.00E+01 8.40E-00 9.30E-00 8.60E-00                      47600
  5  1  2
     2.500       9.585      65.000
  2350.000  2450.000       5.000
```

SPECTRAL DATA: OZONE

N_2 CONTINUUM (H_2O CONTINUUM) OZONE UV AND VISIBLE

Appendix B

Basic Flow Chart for LOWTRAN 2

A general flow chart for LOWTRAN 3 is given in Figure B1 which shows the overall mode of operation of the program. More detailed flow charts are also given for the two main blocks in the program, that is, where the equivalent absorber amounts and refraction calculations are made (Figure B2) and for the transmittance calculation (Figure B3).

The notation used in the flow charts is as follows:

(1) If a condition stated within a given block is fulfilled, then the direction of flow is sideways as indicated by the direction in which the block points (for example, → for the following block).

(2) If the condition stated within a block is not fulfilled, the flow is downwards.

The numbers appearing on the flow charts correspond to the statement numbers given in the main program (see Table A1).

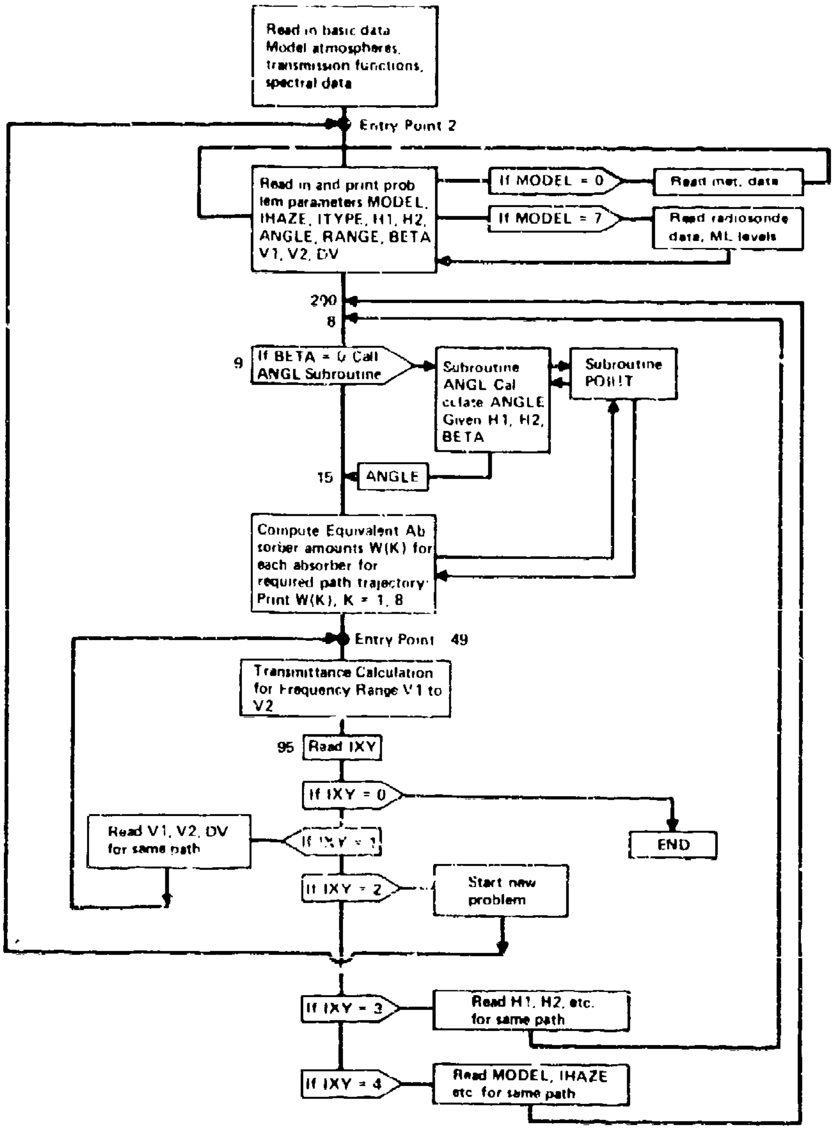


Figure B1. General Flow Chart for LOWTRAN 3

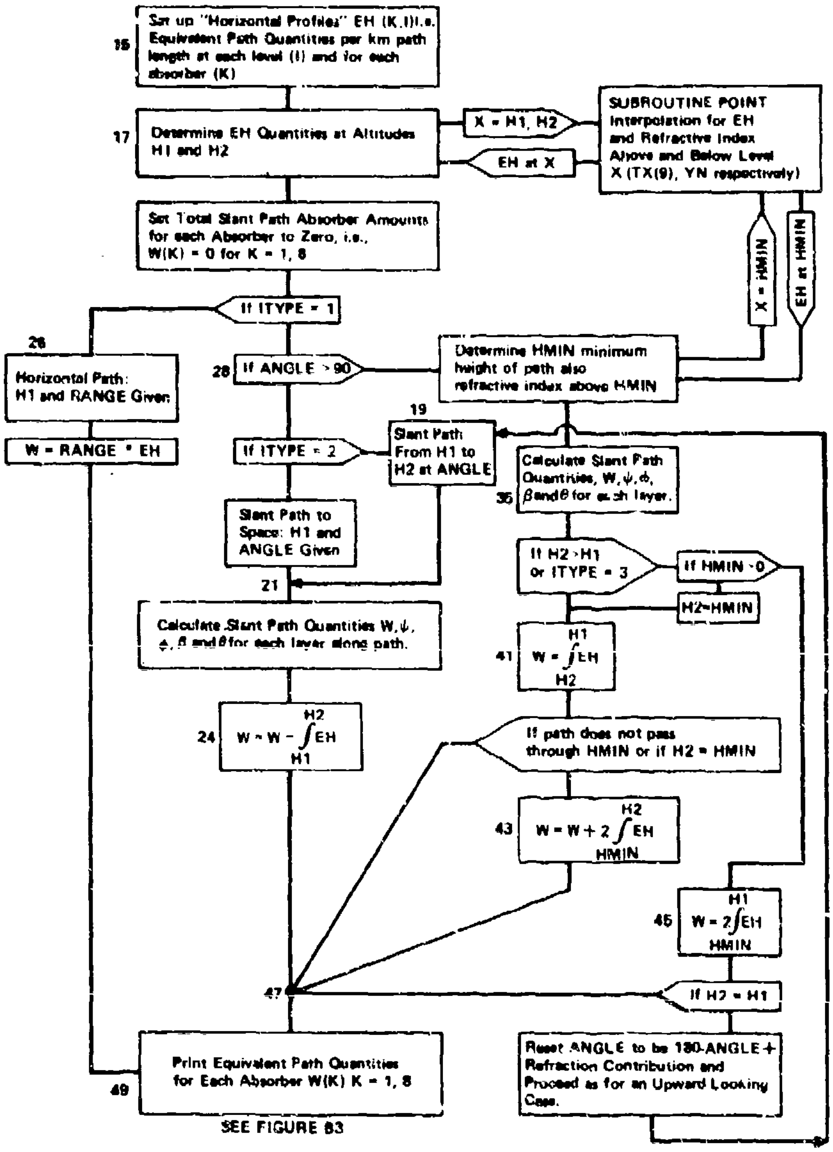


Figure B2. Flow Chart for Calculation of Equivalent Path Quantities

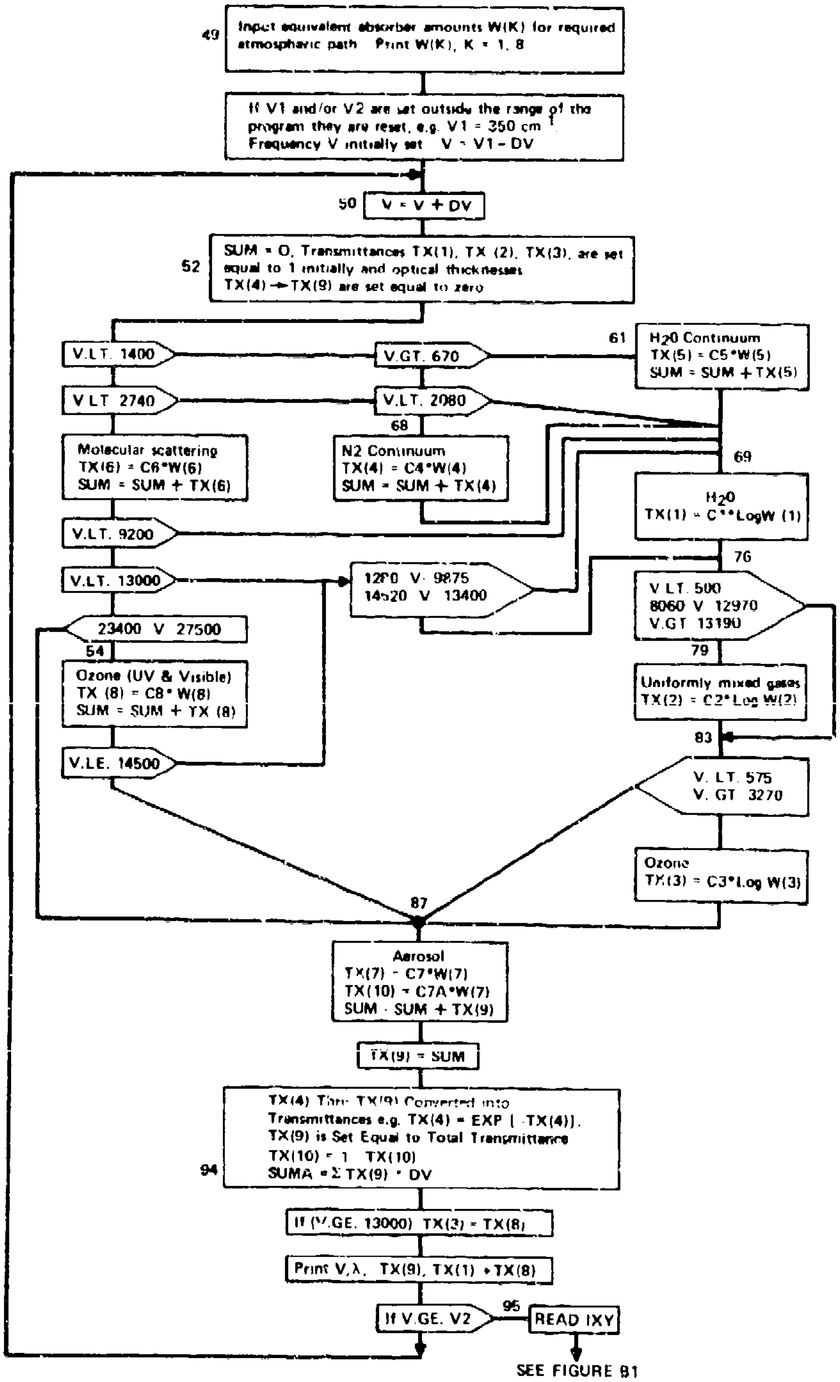


Figure B3. Flow Chart for Transmittance Calculations

Appendix C

Iterative Refraction Scheme Used in Subroutine ANGL

1. INTRODUCTION

An iterative scheme is presented here for determining the initial zenith angle θ_o required for a path trajectory from altitude H1 to H2 for a given earth center angle β_o (see Figure C1), taking into account refraction. The theoretical background for the scheme can be conveniently divided into upward- and downward-looking path trajectories.

2. UPWARD TRAJECTORIES ($\theta_o \leq 90°$)

If we let the geometrical angle θ in Figure C1 be our initial guess for θ_o and use this in the LOWTRAN 3 program, we can calculate the corresponding β, taking refraction into account ($\beta \geq \beta_o$ for upward looking paths). It is apparent that β is a function of θ for a given H1, H2 and model atmosphere. That is:

$$\beta = f(\theta) \ . \tag{C1}$$

We can then differentiate β with respect to θ and write the differential $d\beta = f'(\theta)d\theta$ in the form

$$d\theta = d\beta / f'(\theta) \ . \tag{C2}$$

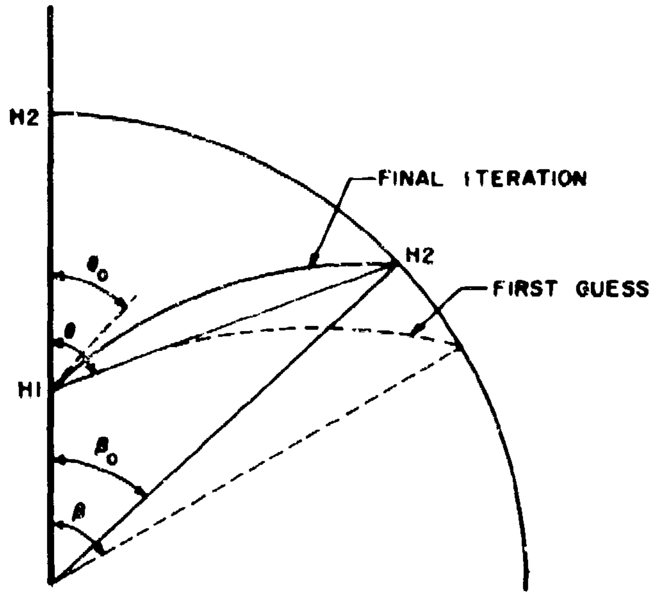


Figure C1. Schematic for Upward Looking Paths Showing: (a) The first guess at the trajectory using the geometrical angle θ from H1 to H2, and (b) the final iteration where $\theta = \theta_o$ and $\beta = \beta_o$

Replacing the differentials by differences, we have

$$\theta' - \theta = (\beta_o - \beta)/f'(\theta) \tag{C3}$$

where θ' is the next guess at θ_o. That is:

$$\theta' = \theta + (\beta_o - \beta)/f'(\theta) \, . \tag{C4}$$

Thus we can substitute θ' in Eq. (C1) and go through the same procedure described above to obtain successive iterations, until θ' converges finally to θ_o when $\beta_o - \beta$ is negligibly small (for example, $< 10^{-7}$ radians). The major unknowns in the above equation are $f(\theta)$ and $f'(\theta)$. From Eqs. (9) and (10) of Section 4.2, it was seen that

$$\beta = \sum_{i}^{m-1} (\theta_i - \alpha_i) = f(\theta) \, . \tag{C5}$$

Thus

$$f'(\theta) = \sum_{i}^{m-1} \left(\frac{d\theta_i}{d\theta} - \frac{d\alpha_i}{d\theta} \right) \tag{C6}$$

where m is the number of levels between H1 and H2. Also from Eq. (7)

$$\sin\theta_i = n_o (R_o + H1) \sin\theta / n_i(R_o + z_i) . \tag{C7}$$

Differentiating the above equation with respect to θ, we have

$$\cos\theta_i \frac{d\theta_i}{d\theta} = n_o(R_o + H1) \cos\theta / n_i(R_o + z_i) .$$

Therefore

$$\frac{d\theta_i}{d\theta} = \frac{\tan\theta_i}{\tan\theta} \tag{C8}$$

assuming that n_i and z_i are independent of θ †. Similarly, it can be shown that

$$\frac{d\alpha_i}{d\theta} = \frac{\tan\alpha_i}{\tan\theta} \tag{C9}$$

so that

$$f'(\theta) = \frac{1}{\tan\theta} \sum_{i}^{m-1} (\tan\theta_i - \tan\alpha_i) . \tag{C10}$$

Equations (C4) and (C10) form the basis for the iteration scheme provided in the subroutine ANGL which contains all the angular calculations given in the main LOWTRAN 2 program for both upward- and downward-looking paths. For an initial guess θ, the quantities β and $f'(\theta)$ are calculated by summing β_i and $\tan\theta_i - \tan\alpha_i$ (defined in Figures 2 and C1) for each layer along the total extent of the path trajectory. Using Eq. (C4), a second guess θ' is obtained and is used to obtain successive θ's until the final value of β is sufficiently close to β_o (for example, to within 10^{-7} radians). When the latter condition is satisfied, the final iteration gives the required initial zenith angle θ_o.

† This assumption holds for upward looking trajectories but not for some downward looking cases where the trajectory passes through the minimum height HMIN (see Figure 3). The latter case will be discussed in the following section.

3. DOWNWARD TRAJECTORIES ($\theta_c > 90°$)

The iteration scheme for determining θ_o for downward looking trajectories is identical to that described above, provided that the path does not pass through the minimum height HMIN [that is, see Figure 3(d)]. If the path does pass through HMIN, however, it is apparent that the refractive index between HMIN and the level above (say, n_m) and HMIN are both dependent on successive guesses of θ.

Consider the case shown in Figure C2 where H2 < H1. For a given initial guess θ, let us divide the contribution to the total angle β into three parts:

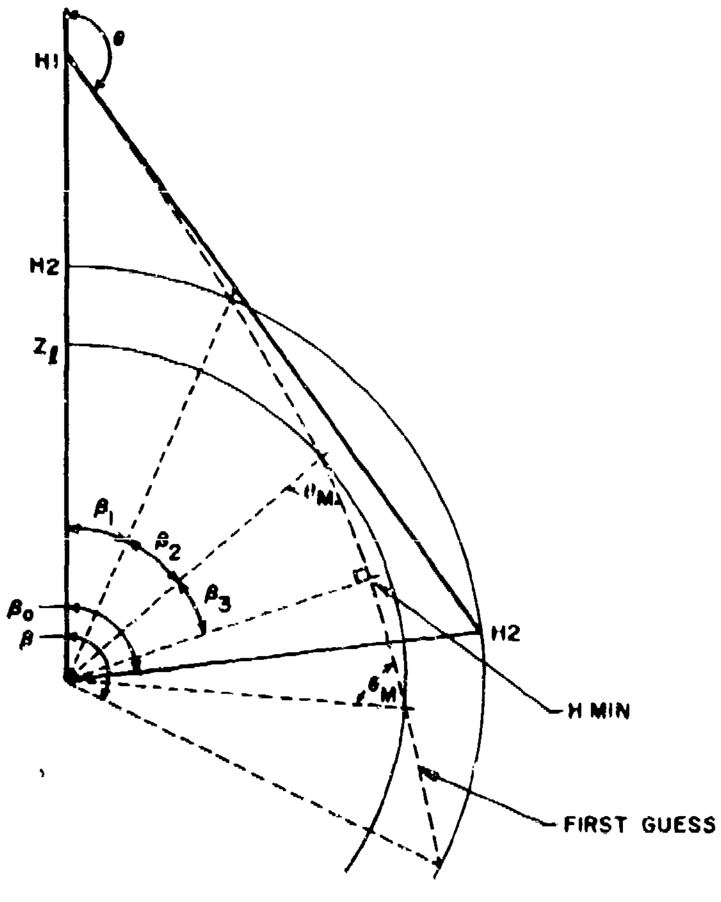


Figure C2. Schematic for Downward Looking Paths Showing the First Guess at the Trajectory Using the Geometrical Angle θ. HMIN is the minimum height for the first iteration, which will be lower than the final value when $\theta = \theta_o$ and $\beta = \beta_o$

β_1, β_2 and β_3. Here β_1 is the angle between H1 and H2 (on the short side of the path), β_2 is the angle between H_2 and the level z_ℓ above HMIN, and β_3 is the angle from z_ℓ to HMIN. That is, $\beta = \beta_1 + 2\beta_2 + 2\beta_3 = f(\theta)$. Then

$$f'(\theta) = \frac{d\beta_1}{d\theta} + \frac{2d\beta_2}{d\theta} + \frac{2d\beta_3}{d\theta}. \tag{C11}$$

Following the same procedure outlined in the previous section, and defining

$$\sin \theta_i = n_o (R_o + H_1) \sin \theta / n_i (R_o + z_i) \tag{C12}$$

where n_o now refers to the mean refraction from H1 to the level below H1, we can show that

$$\frac{d\beta_1}{d\theta} = \frac{1}{\tan \theta} \sum_{j}^{k-1} (\tan \theta_i - \tan \alpha_i) = F_1 \tag{C13}$$

$$\frac{d\beta_2}{d\theta} = \frac{1}{\tan \theta} \sum_{k}^{\ell-1} (\tan \theta_i - \tan \alpha_i) = F_2 \tag{C14}$$

$$\frac{d\beta_3}{d\theta} = -\frac{d\theta_m}{d\theta} = F_3 \tag{C15}$$

(where $\theta_m = 90 - \beta_3$). Now

$$\sin \theta_m = n_o(R_o + H_1) \sin \theta / n_m(R_o + z_\ell) \tag{C16}$$

where n_m is the refractive index between HMIN and z_ℓ. Differentiating Eq. (C16) with respect to θ and dividing by $\cos \theta_m$, we have

$$\frac{d\theta_m}{d\theta} = \frac{\tan \theta_m}{\tan \theta} - \frac{\tan \theta_m}{n_m} \left(\frac{dn_m}{d\theta}\right). \tag{C17}$$

We will now digress for a moment to show some relationships between HMIN, n_m and θ, which will assist us in defining the quantity $dn_m/d\theta$. If we let $X = R_o + \text{HMIN}$ and write

$$\frac{dn_m}{d\theta} = \frac{dn_m}{dX} \cdot \frac{dX}{d\theta} \tag{C18}$$

then clearly dn_m/dX is the mean refractive index gradient above HMIN, which we can specify for a given model atmosphere. The other parameter $dX/d\theta$ defines the variation of HMIN with θ.

Applying Eq. (C12) and replacing n_i, z_i and θ_i by n_m, HMIN and $\pi/2$ respectively, we have

$$n_m X = n_o (R_o + H1) \sin \theta . \tag{C19}$$

Differentiating Eq. (C19) with respect to θ and using Eq. (18), it will be seen that

$$\frac{dX}{d\theta} = \left[\left(\frac{1}{X} + \frac{1}{n_m} \frac{dn_m}{dX} \right) \tan \theta \right]^{-1} . \tag{C20}$$

Also, if we assume that $n - 1$ varies exponentially with altitude where n is the mean refractive index, then the refractive index gradient is given by

$$\frac{dn}{dX} = - \frac{n-1}{H}$$

where H is a scale height parameter which can be defined as follows:

$$H = (z_i - z_{i-1})/\log_e \left\{ (n_{i-1} - 1)/(n_i - 1) \right\} .$$

Therefore

$$\frac{dn_m}{dX} = - \left(\frac{n_m - 1}{z_i - \text{HMIN}} \right) \log_e \left(\frac{n_m - 1}{n_i - 1} \right) . \tag{C21}$$

Using Eqs. (C18) through (C20) and substituting for $dn_m/d\theta$ in Eq. (C17), we have

$$\frac{d\theta_m}{d\theta} = \frac{\tan \theta_m}{\tan \theta} \left[1 - \frac{1}{n_m} \frac{dn}{dX} \Big/ \left(\frac{1}{X} + \frac{1}{n_m} \frac{dn}{dX} \right) \right] . \tag{C22}$$

Thus we can now write Eq. (C15) in terms of known quantities:

$$F_3 = - \frac{\tan \theta_m}{\tan \theta} \left[1 - \left(1 + n_m \Big/ X \frac{dn_m}{dX} \right)^{-1} \right] . \tag{C23}$$

The final expression for the iteration scheme for the general case where H2 < H1 and $\theta > 90^{o}$ is

$$\theta' = \theta + (\beta_o - \beta)/(F_1 + 2F_2 + 2F_3) \tag{C24}$$

where F_1, F_2 and F_3 are defined in Eqs. (C13), (C14) and (C23). For the case where $\theta > 90^{o}$ and H2 > H1, the above expression would become

$$\theta' = \theta + (\beta_o - \beta)/(2F1 + 2F3 + F)$$

where F refers to the upward looking contribution from H1 to H2 and is given by

$$F = \frac{1}{\tan \theta_r} \sum_{i=r}^{m-1} (\tan \theta_i - \tan \alpha_i) .$$

In the above expression, θ_r is the angle of refraction at H1. That is

$$\theta_r = \sin^{-1} (n_o \sin \theta / n_o')$$

where n_o' and n_o are the mean refractive indices of the layers above and below H1 respectively, and θ is the current initial zenith angle guess.

Appendix D

Symbols and Definitions

AB	Absorption at frequency ν, also average transmittance
AHAZE	Aerosol number density for MODEL = 7
AHZZ	Aerosol number density for MODEL = 7
AJ	Equivalent absorber amount per km at level J
ALAM	Wavelength (μm)
ALP	Angle of arrival at adjacent level
ANGLE	Input zenith angle (degrees) [compare with θ_0 in the text]
AO	Constant A defined in Eq. (10); that is, $(R_0 + H)n_0 \sin \theta_0$
AVW	Average wavelength used in refractive index expression
BET	Angle subtended at the earth's center as path traverses adjacent levels [cf β_i in Eq. (8)]
BETA	Total angle subtended by path at earth's center [compare β in Eq. (9)]
BJ	Equivalent absorber amount per km at level J + 1
CA	Conversion factor from degrees to radians
CO	Wavelength dependent coefficient used in refractive index expression
CW	Wavelength dependent coefficient used in refractive index expression
C1	Log absorption coefficient for water vapor
C2	Log absorption coefficient for uniformly mixed gases
C3	Log absorption coefficient for ozone
C4	Absorption coefficient for nitrogen (~4 μm)
C5	Absorption coefficient for water vapor continuum (~10 μm)
C6	Extinction coefficient for molecular scattering

Preceding page blank

C7	Extinction coefficient for aerosol models
C7A	Aerosol absorption coefficient
C8	Absorption coefficient for ozone (UV and visible regions)
D	Water vapor amount (pr. cm/km) at level I
DP	Dew point temperature (°C)
DS	Path length from level I to Level I + 1
DV	Wavenumber increment at which transmittance is calculated
DZ	Height increment from level I to level I + 1
E(K)	Equivalent absorber amounts per km at height H1 [see ω^* in Eq. (2)]
EH(1, I)	Equivalent absorber amount per km for H_2O at level Z(I)
EH(2, I)	Equivalent absorber amount per km for $CO_2 + N_2O$ etc at level Z(I)
EH(3, I)	Equivalent absorber amount per km for O_3 at level Z(I)
EH(4, I)	Equivalent absorber amount per km for N_2 at level Z(I)
EH(5, I)	Equivalent absorber amount per km for H_2O continuum at level Z(I)
EH(6, I)	Equivalent absorber amount per km for molecular scattering at level Z(I)
EH(7, I)	Equivalent absorber amount per km for aerosol extinction at level Z(I)
EH(8, I)	Equivalent absorber amount per km for ozone (UV and visible) at level Z(I)
EH(9, I)	Mean refractive index of layer above level Z(I)
EV	Integrated absorber amount from level I to level I + 1 [cf W_i defined in Eq. (15)]
F	Function for determining saturation vapor density of water (gm m^{-3})
FO	Transmission function logarithmic absorber amount scale for O_3
FW	Transmission function logarithmic absorber amount scale for H_2O and the uniformly mixed gases
H1	Initial altitude (km)
H2	Final altitude (km)
HAZE	Aerosol number density (no. cm^{-3})
HM	Estimated tangent height (km)
HMIN	Minimum altitude of path trajectory (km)
HZ1	Aerosol number density (no. cm^{-3}) for 23 km visual range
HZ2	Aerosol number density (no. cm^{-3}) for 5 km visual range
I	Running integer used as altitude (level) indicator and frequency indicator
IATM	Number of levels in model atmosphere
IDV	Frequency increment (cm^{-1})
IFIND	Indicator for using subroutine ANGL
IHAZE	Aerosol model indicator
IM	Parameter used when reading in a new atmospheric model (see Section 5.2.1)
IP	Indicator for using subroutine POINT to calculate refractive index only (IP = 0) or equivalent absorber amounts also (IP ≠ 0).

ITYPE	Indicator for type of atmospheric path (see Section 5.1)
IV	Frequency at which transmittance is calculated
IV1	Starting frequency (equivalent to V1—see Section 5.1)
IV2	Last frequency (equivalent to V2—see Section 5.1)
IXY	Parameter for terminating program and cycling indicator (see Section 5.1)
J	Running integer for altitude identification
JMIN	Altitude indicator for minimum height of path
JP	Print option parameter
J1	Level indicator for altitude H1
J2	Level indicator for altitude H2
K	Absorber indicator, K = 1, 2, 3, etc., corresponds to H_2O, uniformly mixed gases, O_3 etc. respectively
K1	Integer used in reading two model atmospheres on one card
K2	Integer used in reading two model atmospheres on one card and cycling parameter for downward looking paths
K4	Frequency indicator for nitrogen continuum transmittance calculation
L	Frequency indicator for ozone transmittance calculation
LEN	Parameter used for defining longest of two paths (see Section 5.1)
L1	Frequency identifier for UV and visible ozone transmittance calculation
L2	Frequency identifier for UV and visible ozone transmittance calculation
M	Integer used to identify required model atmosphere
ML	Number of levels in radiosonde data input (MODEL = 7)
MODEL	Integer used to identify required model atmosphere (see Section 5.1)
M1	Integer for selecting H_2O altitude profile for (M=M1)
M2	Integer for selecting temperature altitude profile for (M=M2)
M3	Integer for selecting O_3 altitude profile for (M=M3)
N	Indicator for level below given input altitude used in POINT subroutine; also as frequency indicator in UV and visible ozone transmittance calculation
NH	Frequency indicator for water vapor continuum transmittance calculation
NL	Number of levels in model atmosphere data
NP	Indicator for determining whether H1 or H2 coincide with levels in the model atmosphere
NP1	Value of NP for altitude H1
NP2	Value of NP for altitude H2
P(M,I)	Pressure (mb) at level I for model atmosphere M

PHI	Angle of arrival at H2
PI	3.141592654 that is (π)
PPW	Partial pressure of water vapor (in atmospheres)
PS	Total pressure in atmospheres
PSI	Angular deviation of path from initial direction [cf ψ in Eq. (12)]
PT	Product of total pressure (atm) and the square root of 273/T(M, I)
RANGE	Path length (km)
RE	Earth radius (km) (cf R_o in text)
REF	Refractive index of air at level I
RH	Relative humidity (%)
RN	Ratio of refractive indices of air above and below a given level
RO	Earth radius (km) read in as input (= RE)
RX	Ratio of earth center distances between adjacent levels
R1	The product of the sine of the initial zenith angle and the earth center distance to starting altitude
SALP	Sine of angle of arrival at adjacent level (cf sin α)
SPHI	Sine of the local zenith angle at a given level (cf sin θ)
SR	Slant range (km)
SUM	Sum of the optical thicknesses of absorbers 4 through 8
SUMA	Accumulated integrated absorption
T(M, I)	Temperature (°K) for model atmosphere M at level I
THET	Zenith angle at a given level (in radians)
THETA	Zenith angle at a given level (in degrees)
TMP	Ambient temperature (°C)
TR	Transmittance scales for transmission functions
TS	Ratio of standard temperature (273.0°K) to temperature at level I
TT	Ratio 273.15/(TMP + 273.15)
TX(K)	Equivalent absorber amounts per km at a given altitude obtained from POINT; also transmittance values at a given wavelength for each absorber type (K = 1, 8)
TX(9)	Total transmittance at frequency V
TX(10)	Absorption due to aerosol only at frequency V
TX1	Refractive index of layer above initial altitude H1
TX2	Refractive index of layer above final altitude H2
TX3	Refractive index of layer above minimum altitude HMIN
V	Running frequency (cm^{-1})
VH(K)	Integral of the equivalent absorber amounts from H1 to level I
VIS	Visual range (km) at sea level
VX	Wavelength at which aerosol coefficients are read in (μm)
V1	Initial frequency for transmittance calculation, cm^{-1}
V2	Final frequency for transmittance calculation, cm^{-1}

W(K)	Total equivalent absorber amount for entire path
WH(M, I)	Water vapor density for atmospheric model M at level I (gm m^{-3})
WO(M, I)	Ozone density for atmospheric model M at level I (gm m^{-3})
WS1	Transmission function scaling factor for H_2O at given wavelength
WS2	Transmission function scaling factor for CO_2, etc., at given wavelength
WS3	Transmission function scaling factor for O_3 at given wavelength
W2	Water vapor density for atmospheric model M at level I + 1 (gm m^{-3})
X	Input height to POINT subroutine
XD	Wavenumber interpolation parameter in UV ozone transmittance calculation
XH	Wavenumber interpolation parameter in H_2O continuum calculation
XI	Wavenumber interpolation parameter
XX	Wavenumber identification parameter for UV ozone transmittance calculation
X1	Earth center distance of level I
X2	Earth center distance of level I + 1
Y	Input zenith angle in radians
YN	Refractive index of layer below input height from POINT subroutine
YN1	Refractive index of layer below initial altitude H1
YN2	Refractive index of layer below final altitude H2
YY	Aerosol absorption coefficient at frequency V
Z(I)	Altitude at level I in km

☆ U. S. GOVERNMENT PRINTING OFFICE: 1975--600-223--12